Atlantic Richfield Company

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December 31, 2013

Mr. Steven Way
On-Scene Coordinator
Emergency Response Program (8EPR-SA)
U.S. EPA, Region 8
1595 Wynkoop Street
Denver, CO 80202-1129

RE: Evaluation of Source Water Controls Report
**   Rico-Argentine Mine Site – Rico Tunnels, Operable Unit OU01**
**   Dolores County, Colorado**

Dear Mr. Way:

On behalf of Atlantic Richfield Company (Atlantic Richfield), please find enclosed the *Evaluation of Source Water Controls Report* (report) prepared for the Rico-Argentine Mine Site (site). This report was performed pursuant to the requirements in Task E – Source Water Investigation and Controls / Subtask E3 – Evaluation of Hydraulic Controls Alternatives accompanying the Unilateral Administrative Order for Removal Action, Rico-Argentine Site, Dolores County, United States Environmental Protection Agency, Region 8, (U.S. EPA), dated March 9, 2011 (Docket No. CERCLA-08-2011-0005).

This report evaluates potential methods for decreasing contaminant discharge from the St. Louis Tunnel by controlling mine water flow rates and/or concentrations. Available flow and chemical concentration data were reviewed for the sources that contribute to the St. Louis Tunnel discharge, including the Blaine Tunnel, Southeast Cross-cut, and Northwest Cross-cut. Potential hydraulic control methods to reduce or eliminate flows were evaluated, and the results of the 2012 and 2013 alkaline solution injection tests were summarized and evaluated. Complete results of the 2012 and 2013 St. Louis Tunnel Discharge Source Mine Water Treatability Studies will be presented in a forthcoming completion report that will be submitted to the U.S. EPA by March 31, 2014.

If you have any questions regarding this report, please feel free to contact me at (714) 228-6770 or via e-mail at Anthony.Brown@bp.com.

Sincerely,

Tony Brown
Project Manager Mining
Atlantic Richfield Company

Enclosure: *Evaluation of Source Water Controls Report*

A BP affiliated company

cc: Ronald Halsey, Atlantic Richfield Company (via e-mail)
        Terry Moore, Atlantic Richfield Company (via e-mail)
        Sheila D'Cruz, Atlantic Richfield Company (via e-mail)
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EVALUATION OF SOURCE WATER CONTROLS
Rico-Argentine Mine Site – Rico Tunnels
Operable Unit OU01
Dolores County, Colorado

Prepared for:
Atlantic Richfield
La Palma, California

Prepared by:
AMEC Environment & Infrastructure, Inc.
Rancho Cordova, California

December 2013

Project No. SA11161313

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LIST OF ACRONYMS

AMEC	AMEC Environment & Infrastructure, Inc.
Atlantic Richfield	Atlantic Richfield Company
C	concentration
$CaCO_3$	calcium carbonate
CDRMS	Colorado Division of Reclamation, Mining and Safety
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
cfs	cubic feet per second
DR-3	St. Louis Tunnel discharge monitoring location
DR-3A	St. Louis Tunnel discharge injection test sampling location
DR-6	St. Louis Ponds effluent sampling location
DR-G	Dolores River Gaging Station
ft/hr	feet per hour
gpm	gallons per minute
HRT	hydraulic residence time
IBF	in-by flume
K_2CO_3	potassium carbonate
lbs/day	pounds per day
mg/L	milligram per liter
mV	millivolts
NaOH	sodium hydroxide
NE	northeast
NPDES	National Pollutant Discharge Elimination System
NW	northwest
OBF	out-by flume
ORP	oxidation reduction potential
Q	flow rate
RAWP	Removal Action Work Plan
report	Evaluation of Source Water Controls Report
SE	southeast
site	Rico-Argentine Mine Site – Rico Tunnels, Operable Unit OU01
U.S. EPA	United States Environmental Protection Agency
UAO	Unilateral Administrative Order
µg/L	micrograms per liter
%	percent

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EXECUTIVE SUMMARY

This *Evaluation of Source Water Controls Report* (report) summarizes the available information on the sources of water and contaminants that discharge from the St. Louis Tunnel at the Rico-Argentine Mine Site – Rico Tunnels, Operable Unit OU01, in Dolores County, Colorado (site). Potential methods for reducing contaminant loading by controlling mine water flow rates and/or concentrations are evaluated.

The St. Louis Tunnel discharge originates as precipitation that infiltrates into the subsurface and migrates along fractures and faults. Water collects in the mine workings, may react with mineralized materials, and drains to the St. Louis Tunnel. The primary mine workings contributing to drainage from the St. Louis Tunnel are the Northwest (NW) Cross-cut (12% to 25% of the flow), the Southeast (SE) Cross-cut (39% to 82% of the flow), and the 145 Raise (less than 10% of the flow), though groundwater infiltration into the St. Louis Tunnel (downgradient of the cross-cuts) may contribute a substantial part of the discharge. Available analytical data indicates that the NW Cross-cut contributes the majority of zinc, cadmium, and manganese.

Based on currently available information, there are no readily accessible locations to install bulkheads or plugs for hydraulic control of mine water. Control measures in the accessible part of the Blaine Tunnel would not reduce the hydraulic loading at the St. Louis Tunnel significantly. Although the existence of major faults is known and infiltration through these features is presumed to occur, evaluation of their accessibility for grouting, their distribution and extent, and the extent to which grouting would reduce water flow to the St. Louis Tunnel was beyond the scope of this investigation.

Injection of alkaline solutions into the 517 Shaft during 2012 and 2013 reduced concentrations in the shaft to near zero concentrations and decreased concentrations of zinc, cadmium, manganese, and other metals at the St. Louis Tunnel discharge. Total alkalinity and pH increased and metals concentrations decreased in the 517 Shaft. Metals concentrations at the St. Louis Tunnel discharge were decreased by up to 40% during the 2012 injection of potassium carbonate and by as much as 26% during the 2013 injection of sodium hydroxide. The contaminant load from the SE Cross-cut was treated during both injection tests, and the contaminant load from the NW Cross-cut was partially treated during the 2012 test.

No further testing of in-situ chemical treatment is recommended at this time. If the other water treatment alternatives that currently are being evaluated for the site do not provide sufficient treatment for the St. Louis Tunnel discharge, in-situ chemical precipitation could be revisited. Future development of this treatment method could focus on identifying a better injection location and improving chemical delivery methods.

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EVALUATION OF SOURCE WATER CONTROLS
Rico-Argentine Mine Site – Rico Tunnels, Operable Unit OU01
Dolores County, Colorado

1.0   INTRODUCTION

This *Evaluation of Source Water Controls Report* (report) has been prepared by AMEC
Environment & Infrastructure, Inc. (AMEC), on behalf of Atlantic Richfield Company (Atlantic
Richfield), to describe recent efforts to understand and evaluate the sources of water and
contaminants that discharge from the St. Louis Tunnel portal at the Rico-Argentine Mine Site –
Rico Tunnels, Operable Unit OU01 (site). The site is located in the San Juan Mountains of
southwestern Colorado, just north of the Town of Rico in Dolores County, Colorado (Figures 1-1
and 1-2). The site consists of the St. Louis Tunnel and associated complex of underground mine
workings and a series of settling ponds (Figures 1 through 4 of Attachment 1).

In 2011, the United States Environmental Protection Agency (U.S. EPA) issued a *Unilateral
Administrative Order for Removal Action (UAO), Comprehensive Environmental Response,
Compensation and Liability Act (CERCLA) Docket No. 08-20011-0005* (U.S. EPA, 2011a). The
UAO requires Atlantic Richfield "to conduct removal actions … to abate an imminent and
substantial endangerment to the public health or welfare or the environment that may be
presented by the actual or threatened release of hazardous substances at or from the Site."

The UAO includes the Removal Action Work Plan (RAWP; U.S. EPA, 2011b), which describes
specific investigations and removal action tasks to be completed for the site. Task E of the
RAWP requires that Atlantic Richfield evaluate the sources of water that enter the mine
workings and discharge at the St. Louis Tunnel and evaluate potential control methods for
reducing or eliminating flows that contribute to the discharge. This report has been prepared to
fulfill the reporting requirements of Subtask E3, "Evaluation of Hydraulic Controls Alternatives."
This subtask includes an evaluation of methods to reduce flows into and/or contamination of
water flowing through the mine workings.

1.1   OVERVIEW AND OBJECTIVES

The main objectives of this report are to summarize the available investigation data on the
sources of water and contaminants that discharge from the St. Louis Tunnel and to evaluate
potential methods for controlling the flow of water and/or the discharge of contaminants. This
report presents the current understanding of the sources of water and contaminants and
evaluates potential methods for reducing contaminant loading by controlling flow rates and/or

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concentrations that discharge from the St. Louis Tunnel. Specifically, this report includes information on the following:

- Layout of the mine workings, sources of water and contaminants within the mine workings, and flow rates and contaminant concentrations at the St. Louis Tunnel discharge (Section 2);

- An evaluation of methods to reduce or control St. Louis Tunnel discharge flows (Section 3);

- An overview of the injection testing that was conducted in 2012 and 2013 to evaluate in-situ chemical precipitation to reduce contaminant concentrations in the St. Louis Tunnel discharge (Section 4); and

- Conclusions and recommendations based on currently available information (Section 5).

2.0   SOURCE WATER CHARACTERIZATION

This section briefly describes the mine workings that are connected to the St. Louis Tunnel. The current understanding of the interconnected mine workings and the sources of water and metals that discharge from the St. Louis Tunnel are described.

2.1   ST. LOUIS TUNNEL AND RICO-ARGENTINE MINE WORKINGS

The original portal of the St. Louis Tunnel was located at the western base of Telescope Mountain above the relatively flat Dolores River valley (Figure 1-1). The average elevation of the valley (as significantly modified by previous mining and minerals processing activities) is about 8,800 feet above mean sea level. The St. Louis Tunnel drains historical mine workings that extend into Telescope Mountain to the north and Dolores Mountain to the southeast. The interconnected mine workings have been partially mapped by AECOM, based on historic surveys of mine workings (Attachment 1). Mine water that continuously discharges from the St. Louis Tunnel flows through a series of settling ponds before discharging to the Dolores River at monitoring location DR-6, approximately 0.2 mile upstream of the bridge at Colorado State Highway 145, north of the Town of Rico (Figures 1-1 and 1-2).

The St. Louis Tunnel was originally driven through about 330 feet of colluvium at the base of CHC Hill and then continued into the bedrock of the Hermosa Formation (AECOM, 2013a). Much of the colluvium over the tunnel was subsequently excavated; part of the colluvial section of the tunnel is collapsed and partially plugged with displaced colluvium and damaged timber supports. This debris plug impounds water in the St. Louis Tunnel in a pool that has an

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estimated volume of 670,000 gallons under average flow conditions, although the extent and volume of the pool varies with the inflow from the mine workings (AECOM, 2013b).

The St. Louis Tunnel extends about 4,600 feet northeast into Telescope Mountain, where it intersects the northwest (NW) and southeast (SE) cross-cuts (Figure 1-2). The St. Louis Tunnel continues to the northeast about 500 feet beyond the intersection with these cross-cuts as the 145 Raise. The NW Cross-cut connects the St. Louis Tunnel with the Mountain Spring Mine and other mines in what is referred to herein as the Mountain Springs-Wellington workings, which are generally to the north within Telescope Mountain (URS, 2012).

The SE Cross-cut is approximately 4,400 feet long and connects the St. Louis Tunnel to the extensive interconnected Rico-Argentine Mine workings at the 500 level in the southeastern portion of the site in the vicinity of Silver Creek and Dolores Mountain (Figure 3 of Attachment 1; URS, 2012). For nearly 1,060 feet of its length, the SE Cross-cut is located within or adjacent to the Blackhawk Fault. The workings in the southeastern portion of the site include the Argentine, Blaine (100 level; see Section 2.4), and several levels both above and below the Blaine Tunnel. There are at least five levels below the Blaine Tunnel: the 200, 300, 400, 500 (also referred to as the St. Louis level), 600, and 700 levels. Workings above the Blaine level include the Rico Consolidated middle and upper tunnels, the Argentine Tunnel, the Log Cabin (Blackhawk) Tunnel, and several tunnels above the Log Cabin portal (including the Blacksmith Tunnel). Several of these workings have reportedly collapsed at the portals and have not been accessed recently, with the exception of the Argentine Tunnel (URS, 2012).

At least three vertical shafts are connected to the SE Cross-cut (Figure 3 of Attachment 1). The 517 Shaft is connected to the SE Cross-cut by a short drift at the 500 level; this shaft also connects to four levels of mine workings above the 500 level (the 400, 300, 200, and 100 levels) and two deeper levels (the 600 and 700 levels; Figure 4 of Attachment 1). The Argentine Shaft is located near the 517 Shaft and is also north of Silver Creek (Figure 4 of Attachment 1). This shaft is connected to workings at the 200 and 300 levels and is believed to bottom at the 300 level (URS, 2012). The Number 3 Shaft is located at the Blaine Tunnel level about 1,000 feet inside the Blaine Tunnel from the portal. The top of this shaft is at the Blaine Tunnel (100) level, and it extends down to at least the 300 level. Of these three shafts, only the top of 517 Shaft is considered safely accessible. The top of the 517 Shaft was recently accessed for the 2012-2013 injection testing (Section 4), but the Argentine and Number 3 Shafts have not been inspected recently due to a lack of safe access. During the 2012 investigation activities, the inside of the J-vent above the Argentine Shaft was found to be blocked by debris at the ground surface; thus, the Argentine Shaft could not be inspected. The top of the Number 3 Shaft is located within an inaccessible part of the Blaine Tunnel. In addition to the vertical shafts, there

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are other mine workings (including raises, declines, inclines, winzes, and stopes) that locally interconnect the various levels of the mine workings.

2.2   ST. LOUIS TUNNEL DISCHARGE RATES AND WATER SOURCES

Water that discharges from the St. Louis Tunnel portal originates as precipitation that infiltrates into the subsurface. Although the locations of infiltration to the subsurface have not been well characterized or quantified, much of the infiltration is thought to occur through fractures and faults (e.g., Blackhawk Fault, Princeton Fault, and Last Chance Fault). Some of the infiltration flows into the mine workings and drains through the SE and NW Cross-cuts to the St. Louis Tunnel, while part of the infiltration is stored as groundwater that may eventually flow into the mine workings and ultimately discharge from the St. Louis Tunnel. The relatively consistent isotopic composition of water that discharged from the St. Louis Tunnel between May and October 2011 suggests that this water results from a consistent inflow of groundwater to the mine workings (URS, 2012). The relatively constant base flow of well-mixed, clean groundwater (i.e., groundwater with moderate pH and low concentrations of metals) is apparently augmented by more contaminated flows that infiltrate into the mine workings during spring runoff (URS, 2012).

Some of the water that discharges from the St. Louis Tunnel portal may originate from Silver Creek. URS (2012) found that Silver Creek loses some water in the vicinity of the Blackhawk Fault, probably due to infiltration to faults and fractures. This water may eventually drain to the St. Louis Tunnel and comprise a portion of the discharge, although tracers that were added to Silver Creek were not detectable in the St. Louis Tunnel discharge while monitoring was being conducted. The contribution of Silver Creek to the overall St. Louis Tunnel discharge therefore could not be estimated (URS, 2012).

Water that flows into the mine workings drains downward through the interconnected series of shafts, raises, winzes, declines, inclines, and stopes. Water that is not stored in deep shafts (such as the 517 Shaft) or that does not exit the mine workings through faults and fractures as groundwater eventually flows to the NW Cross-cut, SE Cross-cut, and 145 Raise (Figure 1 in Attachment 1), which are the primary contributors to drainage from the St. Louis Tunnel. Tracer tests conducted in 2011 confirmed that the 517 Shaft in the southeastern portion of the site is hydraulically connected to the St. Louis Tunnel discharge via the SE Cross-cut (URS, 2012). Although no recent confirmation is available, flow data from Anaconda (1982) and historic mine maps indicate that some portions of the mine workings north of the St. Louis Tunnel in Telescope Mountain are hydraulically connected to the St. Louis Tunnel via the NW Cross-cut.

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Flow observations made from inside the St. Louis Tunnel during August 1980 (Table 2-1; Attachment 2) were reported by Anaconda (1982). These observations indicate that the NW Cross-cut contributed an estimated 25 percent (%) of the flow, the SE Cross-cut contributed about 67% of the flow, and the 145 Raise contributed about 8% of the flow that discharges from the St. Louis Tunnel portal (Anaconda, 1982). It is assumed that these observations were made at the intersection of the St. Louis Tunnel with the other cross-cuts; additional flow may enter as groundwater collected between this location and the St. Louis Tunnel adit[1] (Figure 1 of Attachment 1). Since the St. Louis Tunnel cannot be accessed currently, volumetric contributions to the St. Louis Tunnel discharge have not been measured recently, and there are no recent observations to confirm that the flow proportions reported by Anaconda (1982) are still accurate. Flow proportions are presumed to vary seasonally, given the seasonal flow variations at DR-3 and the inferred primary precipitation infiltration source of the flows.

St. Louis Tunnel discharge measurements are available sporadically between 1973 and 2010 and almost continuously since May 2011. In September 1973, the discharge was approximately 1,400 gallons per minute (gpm; 3.1 cubic feet per second [cfs]). Additional historic flow data is available between July 1979 and May 1983 (Figure 2-1), June 2000 and January 2006 (Figure 2-2), and December 2010 and October 2013 (Figure 2-3). Flow rates in May and August 1995 were estimated to be 990 gpm (2.2 cfs) and 2,200 gpm (4.9 cfs), respectively; the latter estimate is the highest reported St. Louis Tunnel discharge flow rate. The minimum recorded St. Louis Tunnel discharge flow rate is 260 gpm (0.59 cfs) in July 2004. Recently, flow rates at the St. Louis Tunnel portal between May 2011 and October 2013, as measured by converting stage measurements from an ultrasonic level sensor and a submerged pressure transducer installed at the DR-3 flume, ranged from 480 gpm to 910 gpm (1.1 cfs and 2.0 cfs, respectively) and averaged 650 gpm (1.5 cfs).

In 2013, the St. Louis Tunnel discharge (as measured at DR-3) appeared to be stable, with water levels through the flume varying by less than 0.12 inch for months at a time, corresponding to flow rates of 498 gpm to 574 gpm. The cause of this stabilization is unknown, but the lack of seasonal variation may indicate instrument error. Manual flow measurements were performed throughout the summer of 2013 and indicated that flow rates varied from 426 gpm to 570 gpm (Figure 2-3).

Dolores River flow rates have been recorded at a United States Geological Survey (USGS) gauging station (USGS site number 09165000; monitoring location DR-G), located

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[1] Undated geologic mapping of the main St. Louis Tunnel believed to have been prepared in the mid- to late-1950s identified minor seepage in a few locations. Based on the detail and nature of the mapping, it is believed that the existence of major groundwater inflows would have been noted in the mapping.

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approximately 5 miles downstream (south) of DR-6 (Figure 1-1), since 1951. Flow rates in the Dolores River at DR-G vary seasonally, with annual peak flow rates typically occurring in May and June as a result of snowmelt runoff. Flow rates of mine water discharges, as measured at the St. Louis Tunnel (DR-3), also vary seasonally, with generally higher flows during the summer, following the spring snow melt runoff period, and lower flows during the fall, winter, and spring. The peak flow rate from the St. Louis Tunnel (as measured at DR-3) lags behind the peak flow rate in the Dolores River (DR-G; Figures 2-1, 2-2, and 2-3). Dolores River peak flow rates generally occur rapidly over a period of two to four weeks. In contrast, DR-3 flow rates appear to increase gradually with the advent of spring runoff, reach their peak five to ten weeks after peak flow in the Dolores River, and remain high over longer periods of time than the Dolores River (nearly two months). Additionally, peak DR-3 flow rate magnitudes generally correlate to peak DR-G flow rates magnitudes; in years with higher peak flow rates measured at DR-G, higher peak flow rates also are measured at DR-3.

These flow rate trends indicate that the St. Louis Tunnel discharge likely is impacted, if not largely controlled, by infiltration of snowmelt into groundwater. In years with greater winter precipitation[2] and/or higher snowmelt runoff, as measured at DR-G, higher flow rates may be anticipated at DR-3 (Figures 2-2 and 2-3). St. Louis Tunnel discharge rates may be predictable based on Dolores River flow trends, as described in Section 5 of AECOM (2013b).

2.3   ST. LOUIS TUNNEL CONTAMINANT DISCHARGE AND CONTRIBUTIONS

Mine water that discharges from the St. Louis Tunnel has elevated concentrations of several metals, notably cadmium, manganese, and zinc. As with the flow contributions from the NW Cross-cut, SE Cross-cut, and 145 Raise, there is no specific, recent information on the contributions of metal loadings from each of these sources. However, the Anaconda (1982) memorandum included analytical data for several analytes (Table 2-1), allowing an estimation of mass loading contributions from the three sources that drain into the St. Louis Tunnel. The reported zinc concentrations ranged from 0.50 milligram per liter (mg/L) from the 145 Raise to 27 mg/L in the NW Cross-cut (Table 2-1). Based on the reported flow proportions and concentrations, the NW Cross-cut contributes 4.5 times more cadmium, 3.9 times more zinc, and 10 times more iron load than the SE Cross-cut, whereas the SE Cross-cut contributes 1.3 times as much sulfate load as the NW Cross-cut. The 145 Raise is a minor contributor to both flow and contaminant load.

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[2] Annual cumulative precipitation data was obtained from the Scotch Creek SNOTEL site (NRCS, 2013), located approximately four miles south of the site. Annual cumulative precipitation is reported by water year beginning annually on October 1. Precipitation data for the Scotch Creek SNOTEL site is available from October 1985 to present.

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When the zinc concentrations reported by Anaconda (1982) are combined with the estimated flow proportions (25% from the NW Cross-cut, 67% from the SE Cross-cut, and 8% from the 145 Raise) to calculate mass loading rates (mass per day) from each source, the mass balance does not converge (i.e., the sum of the zinc mass loading contributed by the three sources does not equal the zinc mass exiting the St. Louis Tunnel).

$$Q_{NW}C_{NW} + Q_{SE}C_{SE} + Q_{145}C_{145} = Q_{SLT}C_{SLT}$$

where each Q is a flow rate and each C is a concentration. The subscripts refer to the different sampling locations: NW refers to the NW Cross-cut; SE refers to the SE Cross-cut; 145 refers to the 145 Raise; and SLT refers to the St. Louis Tunnel.

$$\frac{1}{4}Q_{SLT}(27\ mg/L) + \frac{2}{3}Q_{SLT}(2.62\ mg/L) + \frac{1}{12}Q_{SLT}(0.50\ mg/L) = Q_{SLT}(5.2\ mg/L)$$

Dividing by Q_{SLT} yields:

$$6.75 + 1.75 + 0.04 \neq 5.2$$

Mass balance calculations with other analytes (including fluoride, which is likely to be conservative) result in similar discrepancies. There are several possibilities for the inequality of this mass balance calculation. The reported analytical results could be inaccurate; the analytes may not have been conservative due to precipitation, co-precipitation, or sorption within the St. Louis Tunnel or during sample transport;[3] or the estimated flow proportions or total flow may have been inaccurate. The flow proportions are reported as "Estimated portion of flow" (Anaconda, 1982), and the location and methods for these estimates are uncertain. The flows were apparently not measured, which may have resulted in substantial errors in the estimated relative flow contributions from each source. The contributing flows also may have been diluted by relatively clean inflow to the St. Louis Tunnel between the intersection and the portal, although historical information does not indicate substantial inflow to the St. Louis Tunnel. The possible inaccuracies in the reported flow estimates are discussed in the following paragraphs.

Assuming that the estimated flow proportions reported by Anaconda (1982) are inaccurate, the flow and mass balances converge. It is not unreasonable, based on available information, to assume that the flow and contaminant mass contributions from the NW Cross-cut, SE Cross-cut, and 145 Raise contribute essentially all of the flow and contaminant mass that discharges from the St. Louis Tunnel. Thus, the flow and mass balances should both converge (i.e., inputs at the tunnel intersection with the three sources should equal outputs at DR-3). In an effort to

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[3] According to the historical documents in Attachment 2, samples were taken on August 18, 1980, and received by the lab on August 25, 1980.

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force the mass balance to converge, the Solver function in Microsoft Excel was used to vary the contributing flow proportions to minimize the discrepancies in the mass balances (Table 2-2). Under this scenario, the NW Cross-cut contributes only 12% of the flow (as compared to the reported approximately 25%) but the majority of the zinc, cadmium, and iron. The SE Cross-cut contributes 82% (versus the reported 67%) of the flow and most of the sulfate. The 145 Raise contributes less than 10% (consistent with the reported estimate of about 8%) of the flow and mass for all constituents considered. Results of this least squares optimization procedure are summarized in Table 2-2.

An additional possibility is that the flow proportions reported by Anaconda (1982) do not account for inflow between the tunnel intersection and the St. Louis Tunnel portal. If the flow proportions were estimated at the intersection of tunnels, inflow to the St. Louis Tunnel from fractures or drill holes (Anaconda, 1985) between the intersection and the portal (a distance of about 4,400 feet) were not included. Assuming that contaminant concentrations in any St. Louis Tunnel groundwater inflow are relatively low, the concentrations emerging from the St. Louis Tunnel would be diluted relative to the expected concentrations at the tunnel confluence.

Based on these flow assumptions and an assumption that the zinc concentration in the St. Louis Tunnel inflow between the tunnel intersection and the portal is relatively low (0.5 mg/L, equal to the concentration in the flow from the 145 Raise), mass balances on the analytes listed in Table 2-1 indicate that inflow to the St. Louis Tunnel may contribute as much as 40% of the flow that discharges from the portal. Under this scenario, zinc that discharges from the St. Louis Tunnel portal is primarily from the NW Cross-cut (76% of the zinc mass, 15% of the DR-3 flow), with lower mass contributions from the SE Cross-cut (20% of the zinc mass, 39% of the DR-3 flow), the 145 Raise (less than 1% of the zinc mass, 5% of the DR-3 flow), and the St. Louis Tunnel inflow (4% of the zinc mass, 42% of the DR-3 flow).

Although the flow and mass contributions cannot be verified due to lack of access for sampling and flow measurement and the mass balances do not account for possible losses of metals within the mine workings, these results suggest that the NW Cross-cut contributes a substantial fraction of the contaminant mass that discharges from the St. Louis Tunnel, while the SE Cross-cut apparently contributes most of the flow.

2.4   BLAINE TUNNEL SOURCE AREA

The Blaine Tunnel was originally thought to be a major contributor of mine water and contaminants that discharge from the St. Louis Tunnel portal. This section describes historical information, recent rehabilitation work, and the results of recent investigations at the Blaine Tunnel. As described below and summarized in Section 2.4.7, it appears that the Blaine Tunnel

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portal area may not be a major contributor to the loads of the primary metals of interest (i.e., zinc, cadmium, and manganese) in the St. Louis Tunnel discharge.

2.4.1   Blaine Tunnel Description

The Blaine Tunnel portal is located south of Silver Creek (Figure 3 of Attachment 1). The tunnel (at the 100 level) extends about 3,750 feet southeast into Blackhawk Mountain, with workings that span about 1,300 feet north to south and 2,300 feet east to west (Burack, 1982). Several faults intersect the tunnel, including the Blackhawk fault, Last Chance fault, and numerous minor faults and localized fractures (Burack, 1982). These faults and fractures may provide flow paths for infiltration into the Blaine Tunnel and/or the lower mine workings (200, 300, 400, and 500 [St. Louis/SE Cross-cut] levels). The Blaine Tunnel also intersects at least one vertical shaft, the Number 3 Shaft, which likely provides a vertical flow path to at least the lower 200 and 300 levels. The Humboldt Drift branches east off of the Blaine Tunnel approximately 470 feet from the portal and then connects to the Morris-Cook Incline, providing a flow path for water from the Blaine Tunnel directly to the lower levels. Other interconnected drifts, inclines, and stopes potentially provide additional flow paths to the lower mine workings and the SE Cross-cut (Attachment 1).

2.4.2   Blaine Tunnel Historical Discharges

Water historically drained from the Blaine Tunnel and discharged directly to Silver Creek through the 100-level portal. The Blaine Tunnel was one of two permitted discharges at the Rico-Argentine Mine (National Pollutant Discharge Elimination System [NPDES] Permit CO-0029793, outfall 001). In the mid- to late-1970s, mine water in the Blaine Tunnel was diverted underground to the St. Louis Tunnel and subsequently discharged at the St. Louis Tunnel portal, resulting in zero discharge from the Blaine Tunnel (Jahnke, 1977). A concrete cofferdam was installed in 1990 approximately 350 feet inside the Blaine Tunnel from the portal, eliminating direct discharge of mine water from the Blaine Tunnel to Silver Creek (Grayling Environmental, 2006). The concrete cofferdam currently diverts water to the Humboldt Drift and subsequently the Morris-Cook Incline, where it flows downward through interior mine workings to the SE Cross-cut and eventually the St. Louis Tunnel.

2.4.3   2011 Blaine Tunnel Activities

In 2011, the U.S. EPA investigated the Blaine Tunnel as one of the source areas for water and contaminants discharging from the St. Louis Tunnel (URS, 2012). The Blaine Tunnel portal was in poor condition, and leaks in the cofferdam allowed drainage to flow toward the portal. Water entering the Blaine Tunnel via multiple seeps and raises pooled behind the cofferdam, and a blockage restricted flow to the Humboldt Drift, thereby inhibiting drainage from the Blaine Tunnel

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to lower levels. Rehabilitation work was conducted to raise and reinforce the cofferdam and to reinforce the portal to allow safe entry. The tunnel was explored to a distance of about 150 feet beyond the cofferdam; conditions were determined to be unsafe for entry beyond this point (URS, 2012).

Pooled water behind the cofferdam had a pH between 2.0 and 2.5 (URS, 2012). Water samples were collected from the pool in August and October 2011 for analysis of total and dissolved metals, sulfate, and isotopes, but the flow rate to the Humboldt Drift was not quantified. The sample collected in October generally had higher metals concentrations than the sample collected in August. Complete analytical results for Blaine samples are provided in Table 4 of URS (2012). Highlights of the analytical results for the October 2011 sample are as follows:

- Total and dissolved cadmium were detected at concentrations of 953 micrograms per liter (µg/L) and 967 µg/L, respectively.

- Total and dissolved manganese were detected at concentrations of 61,500 µg/L and 61,600 µg/L, respectively.

- Total and dissolved zinc were both detected at 161,000 µg/L.

- Total and dissolved iron were detected at concentrations of 1,390,000 µg/L and 1,420,000 µg/L, respectively.

For each of these metals, the reported total and dissolved concentrations are practically equal, within the limits of analytical precision, indicating that the metals in these samples were present in the dissolved form, as expected in the pH range of 2 to 2.5.

Water flowing into the Blaine Tunnel from a raise located in-by[4] the cofferdam and Humboldt Drift ("flowing raise") was sampled and also had elevated metals concentrations, with concentrations that were similar to or somewhat higher than concentrations in the October 2011 cofferdam pool sample. Water was observed to be flowing into the Blaine Tunnel from the flowing raise at approximately 5 gpm to 10 gpm (URS, 2012). Metals concentrations detected in the Blaine samples were lower than in a sample collected from the Argentine Tunnel (see Section 2.5.1).

A tracer study using fluoride confirmed the hydraulic connection between the Blaine Tunnel and the 517 Shaft (URS, 2012). Fluoride injected into the mine water pooled behind the cofferdam was first detected in the 517 Shaft after approximately 10 hours, while the fluoride peak arrived

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[4] The in-by location denotes a location that is farther into the mine, compared to the cofferdam and Humboldt Drift locations.

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after about 68 hours. Assuming a flow distance of 660 feet, the average velocity of the advection front was about 66 feet per hour (ft/hr), and the velocity of the fluoride peak was about 9.7 ft/hr.

URS (2012) concluded that the Blaine Tunnel is one source of contaminated water to the St. Louis Tunnel. Additional work was recommended to (1) stabilize the Blaine Tunnel cofferdam to prevent surface migration to Silver Creek; (2) remove blockages to allow water from the Blaine Tunnel to flow to the St. Louis Tunnel; (3) install equipment to measure flow rates within the Blaine Tunnel; and (4) perform additional sampling within the Blaine Tunnel to characterize seasonal variations in water quality.

2.4.4   2012-2013 Blaine Tunnel Rehabilitation Work

Rehabilitation work was conducted in the Blaine Tunnel in 2012 and 2013 to stabilize and restore portions of the underground workings, allow mine water to continue to drain to the lower workings and ultimately to the St. Louis Tunnel, and allow further hydrologic characterization of the accessible Blaine workings. The first phase of rehabilitation work was conducted in August and September 2012, and a second phase was completed in August and September 2013. Rehabilitation work was completed and reported by Shannon and Wilson, Inc. (2012, 2013).

During 2012 rehabilitation activities, the U.S. EPA and Colorado Division of Reclamation, Mining and Safety (CDRMS) contractors reconstructed the Blaine Tunnel portal, cleared obstructions to improve access, and added reinforcing along parts of the tunnel. The pool impounded by the Blaine Tunnel cofferdam was dewatered by pumping and discharging more than 14,000 gallons of water to the 517 Shaft. Rehabilitation activities during the 2013 field season focused on the Humboldt Drift and included clearing collapsed areas, installing timber sets to reinforce the walls and roof, and excavating a drainage trench along the floor to encourage mine water to flow down the Humboldt Drift toward the Morris-Cook Incline and presumably to lower levels of the mine workings. During 2013 rehabilitation activities, pooled water was pumped from the Blaine Tunnel to the 517 Shaft, but the pumped volume was not recorded.

2.4.5   Blaine Flow Characterization

Between September 23 and 25, 2012, after dewatering the pool behind the Blaine Tunnel cofferdam, personnel from the CDRMS and URS Operating Services constructed a sandbag berm in the Blaine Tunnel, in-by the cofferdam and Humboldt Drift (Figure 2-4). To quantify the flow of mine water and contaminant loading from the Blaine Tunnel down the Humboldt Drift and the Morris-Cook Incline, a flume (Attachment 3-1) and solar-powered Hach Sigma 950 flow meter with an ultrasonic depth sensor (Attachment 3-2) were installed within the sandbag berm in October 2012. The flume was gauged to measure water depths and corresponding flow rates

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as low as approximately 0.1 gpm. The ultrasonic sensor was installed directly above the flume (Attachment 3-3) for measuring water depths. A data logger was installed outside the Blaine Tunnel to record ultrasonic depth measurements without the need for in-tunnel personnel.

The sandbag berm was constructed at a natural high-point in the Blaine Tunnel floor to capture influent from the "flowing raise" located in-by the Humboldt Drift (Figure 2-4 and Picture 4 of Attachment 3-3). Despite having constructed the sandbag berm out-by (downgradient of) the "flowing raise," additional influent to the Blaine Tunnel was observed during periodic Blaine Tunnel inspections near the vertical timbers in-by the Humboldt Drift (labeled as "inflow" in Figure 2-4 and Picture 1 of Attachment 3-3). This inflow was located out-by the flume and therefore not quantified in flume flow measurements. In addition to this inflow, other influent likely contributes to Humboldt Drift flows; many small drips and seeps within the accessible reaches of the Blaine Tunnel have been reported by in-tunnel personnel. Humboldt Drift flows may be augmented by influent from various other levels of the mine workings, and flow paths other than the Humboldt Drift may connect Blaine out-by the flume (OBF)[5] water to the St. Louis Tunnel discharge. CDRMS observed that water appeared to flow into the workings from behind the Blaine Tunnel flume, suggesting that there may be routes other than the Humboldt Drift for Blaine Tunnel water to flow to the 517 Shaft and SE Cross-cut.[6]

Flow through the flume was first detected on November 25, 2012 (Figure 2-5), indicating that the pool in-by the sandbag berm had re-filled with water after dewatering during rehabilitation and berm construction (Section 2.4.4). Flow rates increased to a maximum of approximately 3.0 gpm on January 18, 2013. Flow rates then decreased throughout February, remained low during March and April, and increased between June and September. The flow rate reached a maximum of 2.8 gpm on September 21, 2013 (Figure 2-5), and decreased thereafter. It is uncertain if the increased flow rates were caused by Blaine Tunnel rehabilitation activities (i.e., dewatering within the Blaine Tunnel) or if these flow rate trends indicate a several month lag between snowmelt in May and June and flow through the Blaine Tunnel, similar to the lag shown in Figure 2-3 and discussed in Section 2.2. Additional water level measurements throughout winter 2013/2014 will help determine if the peak flow rates observed in January 2013 were typical for the Blaine Tunnel or the lingering effect of rehabilitation activities.

2.4.6   Blaine Contaminant Characterization

Water samples were collected from the Blaine Tunnel during 2012 and 2013 to further characterize contaminant concentrations. Analytical results and field parameters are provided in

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[5] The OBF location is out of the mine (downgradient), compared to the flume location.
[6] The Number 3 Shaft, located in-by the Blaine Tunnel flume, is a possible alternative vertical flow path to the SE Cross-cut.

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Table 2-3, and photo documentation of Blaine Tunnel activities is provided in Attachment 3-3. A baseline water sample was collected in-by the cofferdam on September 5, 2012. Later samples were collected after flume construction from flowing water OBF and pooled water in-by the flume (IBF).[7]

Blaine samples collected in 2012 and 2013 generally had low pH, high oxidation reduction potential (ORP), high concentrations of metals and sulfate, and non-detectable alkalinity. In-by flume and OBF results were generally similar. The pH of the samples ranged from 2.0 to 2.6, and the pH of the OBF sample was typically somewhat lower than the pH of the IBF sample for each sampling event. Alkalinity was detected only in the Blaine IBF sample collected on November 14, 2012, but this result is considered erroneous due to the low pH (2.5). Metals and sulfate concentrations in Blaine samples were consistently higher than in samples from the 517 Shaft and the St. Louis Tunnel discharge as sampled at DR-3. OBF samples consistently had higher concentrations of many metals (including zinc, cadmium, manganese, and iron) and sulfate as compared to IBF samples for each sampling event.

2.4.7   Blaine Contaminant Loading

Blaine flume flow data and laboratory analytical results were used to estimate contaminant mass loading to the Humboldt Drift (Table 2-4). Analytical data for OBF water samples were combined with daily average flume flow rates to estimate mass per day contributions to the St. Louis Tunnel discharge. OBF water samples were collected out-by (downgradient) of both the flume and the "inflow" (see Section 2.4.5). Daily average flow rates were calculated from hourly water depth measurements based on the flow rating curve provided by the flume manufacturer (Attachment 3-1). To estimate potential mass loading effects from the "inflow," an assumption was made that "inflow" flow rates may have been as great as measured flume flow rates. Therefore, the mass loading values presented in Table 2-4 provide estimated ranges for mass loading from the Blaine Tunnel to the Humboldt Drift, assuming both the daily average flume flow rate (lower end of the range) and two times the daily average flume flow rate (upper end of the range). These calculations assume that metals are conserved in mine water flowing through the system and that suspended sediments do not settle out of solution. These simplified loading comparisons do not account for attenuation of metals within the mine workings as pH increases to circumneutral during transport from the Blaine to the St. Louis Tunnel discharge.

To account for the many variables that may have governed the Blaine flume and "inflow" flow rates and concentrations, peak mass loading estimates (Table 2-4) were calculated using both the maximum observed analytical results, which typically coincided with the April 2013 sampling

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[7] The IBF location is into the mine (upstream), compared to the flume location.

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event, and the maximum average daily flow rate, which occurred on January 18, 2013, for the limited set of available data. Although the highest flow rates and concentrations did not occur at the same time, these peak mass loading estimates are provided to assess higher mass loadings that could be produced by flow of mine water from this part of the Blaine Tunnel. Higher flow rates may indicate infiltration of less contaminated water (e.g., snow melt), and these higher flows could potentially react with metals in the mine workings, thereby increasing the dissolved metals concentrations.

The highest calculated contaminant loading rates coincided with the peak flow rates observed in September 2013, despite the relatively low metals concentrations observed during the September 2013 water sampling event (Table 2-4). Estimated mass loading ranges for total and dissolved iron and manganese all overlapped substantially with estimated peak mass loading ranges in September 2013. This indicates that periods of higher flow from the Blaine result in higher contaminant loading to the Humboldt Drift and the downstream portions of the workings, even if metals concentrations are lower.

Samples collected from the 517 Shaft (discussed in Section 4) tend to have lower metals concentrations and higher pH as compared to Blaine samples, indicating that mine water from the Blaine Tunnel is partially neutralized during transport to the SE Cross-cut. Some natural attenuation of metals also occurs between the Blaine Tunnel and the SE Cross-cut at the 517 Shaft as pH increases. Mine water from the Blaine Tunnel eventually drains via the SE Cross-cut to the St. Louis Tunnel and exits the mine workings at the St. Louis Tunnel portal near monitoring location DR-3. Thus, contaminant discharge rates from the Blaine Tunnel via the Humboldt Drift can be compared to contaminant discharge rates at DR-3 to assess the relative contribution from the accessible portion of the Blaine Tunnel.

Based on the availability of flow and analytical data for both the Blaine Tunnel and the St. Louis Tunnel discharge, metals loadings can be compared for April 25, June 12, July 10, and August 27, 2013. For these four sampling dates, contaminant discharge rates at DR-3 were calculated (Table 2-4). Contaminant loading rates from the Blaine Tunnel to the Humboldt Drift for select metals then were compared to contaminant discharge rates at DR-3 to conservatively estimate the proportion of contaminants contributed by the Blaine Tunnel source area (Table 2-4). These calculations assume that metals are conserved within the flow pathways, which may introduce significant uncertainty. The results were as follows.

- For the samples that were collected in April 2013, contaminant discharge from the Blaine Tunnel was equivalent to 6% to 12% of the total arsenic discharging from the

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St. Louis Tunnel portal; 8.8% to 17% of the dissolved iron; and no more than 2.1% of the cadmium, manganese, zinc, and total iron.

- In June 2013 (before the start of NaOH injection to the 517 Shaft), contaminant discharge from the Blaine was slightly higher. Total arsenic discharge from the Blaine was equivalent to 7.5% to 15% of the total arsenic discharging from the St. Louis Tunnel portal; up to 4.1% of the cadmium; and no more than 3.1% of the total iron, manganese, and zinc. However, the rate of dissolved iron discharge from the Blaine Tunnel was substantially higher than the dissolved iron discharge rate at DR-3. Other observations have indicated that dissolved iron tends to attenuate by precipitation as iron oxides and oxyhydroxides within the mine workings, resulting in very low dissolved iron concentrations at the St. Louis Tunnel portal.

- The July 2013 sample from DR-3 was most likely affected by the injection test. Contaminant discharge from the Blaine Tunnel was equivalent to 21% to 46% of the total arsenic discharging at DR-3; up to 18% of the total iron; and less than 5% of the cadmium, manganese, and zinc. The rate of dissolved iron discharge from the Blaine Tunnel may have been up to two times the dissolved iron discharge rate at DR-3.

- For the August 2013 samples, contaminant discharge from the Blaine Tunnel was a larger contributor to the DR-3 contaminant discharge as the Blaine flow rate and mass discharge rate both increased. The Blaine Tunnel contributed 27% to 56% of the total arsenic discharging at DR-3; up to 20% of the total iron; up to 11% of the cadmium; less than 7% of the manganese; and no more than 6.4% of the zinc. The rate of dissolved iron discharge from the Blaine Tunnel may have been more than five times higher than the dissolved iron discharge rate at DR-3.

Based on this comparison of contaminant discharge rates from the Blaine and St. Louis Tunnels, the results indicate that the accessible portion of the Blaine Tunnel is not a major source area of cadmium, manganese, or zinc, but the area may be a significant source of arsenic and iron. The discharge rate of dissolved iron from this part of the Blaine is apparently higher than the dissolved iron discharge rate at the St. Louis Tunnel portal, indicating that the high concentrations of dissolved iron from the Blaine attenuate within the mine workings. These calculations do not account for non-measured flow increases or concentration changes during transport down the Humboldt Drift and do not consider contaminant loading from inaccessible areas of the overall Blaine workings.

2.5   OTHER SOURCE AREAS

In addition to the Blaine Tunnel source area, other mine workings that are located south of Silver Creek within Blackhawk Mountain may be additional source areas and may be interconnected to the Blaine Tunnel and/or the SE Cross-cut. This section summarizes available information about these areas.

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2.5.1   Argentine Tunnel Workings

As part of the source characterization activities conducted in 2011, the Argentine Tunnel was entered and investigated (URS, 2012). This tunnel is located south of Silver Creek above the Blaine Tunnel and may be a source of mine water that flows to the Blaine Tunnel and the underlying workings, based on interconnections apparent on historic mine maps. The mine entry team observed both pooled water and flowing water in the tunnel, with accumulations of sediment and sludge, which is thought to be iron oxyhydroxide; however, flow paths could not be determined in the field. Field-measured pH was between 2.0 and 2.5. One water sample that was collected from the Argentine Tunnel (referred to as the "Lower Acidic Pool") had very high concentrations of some metals, indicating that the Argentine Tunnel and other workings above the Blaine Tunnel may be a substantial source of metals loading to the St. Louis Tunnel. Complete analytical results for this sample are provided in Table 4 of URS (2012).

Highlights of the analytical results for the Argentine Tunnel sample are as follows (URS, 2012).

- Total and dissolved cadmium were detected at 11,900 µg/L and 12,000 µg/L, respectively, approximately 12 to 25 times higher than concentrations detected in 2011 samples from the Blaine Tunnel.

- Total and dissolved manganese were detected at 270,000 µg/L and 294,000 µg/L, respectively, approximately 5 to 10 times higher than concentrations detected in 2011 samples from the Blaine Tunnel.

- Total and dissolved zinc were present at 2,390,000 µg/L and 2,460,000 µg/L, respectively, approximately 15 to 40 times higher than concentrations detected in 2011 samples from the Blaine Tunnel.

Based on in-tunnel observations and these analytical results, URS (2012) recommended additional study of the Argentine Tunnel to better characterize flow paths and contaminant concentrations. Based on currently available information, the contribution of contaminants from the Argentine Tunnel to mass discharge at the St. Louis Tunnel cannot be determined.

2.5.2   Other Mine Workings South of Silver Creek

In addition to the Argentine Tunnel, extensive mine workings exist south of Silver Creek, particularly above the Blaine level. Although the existence of these workings is known and historic maps are available, these upper workings have not been recently assessed by direct field investigation. Historic mine maps indicate that essentially all of these mine workings are interconnected. The accessibility of these workings for direct entry and sampling is limited by steep hillsides. Collapsed portals and tunnels and generally unsafe conditions in the unmaintained workings also may prevent entry.

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Although interconnections of these workings with the Blaine Tunnel and the SE Cross-cut likely are present, based on the historic mine mapping, they have not been confirmed in the field. Infiltration and mine water from these workings are believed to drain to the Blaine Tunnel and lower levels and eventually drain to the SE Cross-cut and the St. Louis Tunnel portal. However, the extent to which these workings contribute to volumetric and mass loading at the St. Louis Tunnel is unknown.

3.0   SOURCE WATER HYDRAULIC CONTROL

This section briefly considers potential methods (e.g., plugging tunnels or grouting fractures) for reducing the mine water discharge rate at the St. Louis Tunnel portal by controlling the flow of water within the mine workings. Conceptually, reducing flow of mine water is one method for reducing the rate of contaminant discharge from the St. Louis Tunnel portal. The following discussions assume that the flow proportions reported by Anaconda (1982) are accurate.

3.1   BLAINE TUNNEL

The main Blaine Tunnel has a total length of about 3,750 feet (Burack, 1982). The safely accessible part of the Blaine Tunnel is limited to the no more than about 120 feet in-by the cofferdam, or about 470 feet from the portal (URS, 2012). Thus, most of the Blaine (100) level workings cannot be safely accessed and have not been investigated recently to characterize flows or contaminant loadings. Other than the Blaine Tunnel flume measurements discussed in Section 2.4, there is no information about sources of mine water or flow paths within the Blaine Tunnel.

The accessible part of the Blaine Tunnel contributes relatively small flows and mass loadings (with the exception of arsenic and iron, as shown in Table 2-4) via drainage to the Humboldt Drift. Hydraulic control of these flows or elimination of contaminant mass in flows to the Humboldt Drift would provide little benefit in reducing the overall flows or loadings at the St. Louis Tunnel and thus are not practical.

3.2   SOUTHEAST CROSS-CUT

Based on the August 1980 data, the SE Cross-cut is estimated to contribute about 67% of the flow and about 34% of the zinc that discharges from the St. Louis Tunnel (Anaconda, 1982). Access to the SE Cross-cut from the St. Louis Tunnel is not currently possible due to obstructions at the original St. Louis Tunnel portal area. Direct access from other mine workings to the south of the St. Louis Tunnel, such as the 517 Shaft or the Argentine Shaft, is not safe due to the vertical separation of about 450 feet from ground level near the 517 Shaft to the SE Cross-cut. Furthermore, plugging the SE Cross-cut to reduce discharge at the St. Louis Tunnel

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may have unintended consequences. Hydraulic heads would increase to the south of any plug, which could result in increased groundwater discharge to Silver Creek or discharge of mine water at other locations, potentially increasing metals loading to Silver Creek, although such a hydraulic evaluation has not been conducted.

Mine workings to the south of Silver Creek drain to the SE Cross-cut, based on historic mine maps and tracer testing conducted in 2011 (URS, 2012). These mine workings are the source of a substantial fraction (although apparently not the majority) of the flow that discharges from the St. Louis Tunnel. Access to these mine workings (with the exception of the Argentine Tunnel) has not been attempted recently, and there is limited information about access conditions. Even if these mine workings could be accessed safely, establishing hydraulic controls within the mine workings south of Silver Creek to reduce flows at the St. Louis Tunnel portal would be very difficult to implement and maintain and may have unforeseen consequences.

Based on the current understanding, the SE Cross-cut and the mine workings that drain to the SE Cross-cut are not readily or safely accessible for establishing hydraulic controls. Although methods for controlling contaminant loading from the SE Cross-cut have been investigated (as described in Section 4), the feasibility of establishing hydraulic controls in these parts of the mine workings was not part of this investigation.

3.3   NORTHWEST CROSS-CUT

The flows and loadings contributed by the NW Cross-cut have not been evaluated recently. Based on the August 1980 data, the NW Cross-cut is estimated to contribute about 25% of the flow and about 65% of the zinc discharging from the St. Louis Tunnel (Anaconda, 1982). Access to the NW Cross-cut from the St. Louis Tunnel is not currently possible due to obstructions at the St. Louis Tunnel portal area, and access from other mine workings to the north of the St. Louis Tunnel has not been assessed. The feasibility of establishing hydraulic controls in the mine workings to the north of the St. Louis Tunnel was not part of this investigation; thus, the potential for reducing or controlling flows and/or contaminants that are contributed by the NW Cross-cut cannot be assessed at this time.

3.4   145 RAISE

The 145 Raise appears to be a dead-end raise and cannot be accessed for assessment. Based on the August 1980 data, the 145 Raise is estimated to contribute about 8% of the flow and less than 1% of the zinc that discharges from the St. Louis Tunnel (Anaconda, 1982). Access to the 145 Raise from the St. Louis Tunnel is not currently possible due to obstructions at the St. Louis Tunnel portal. Potential access from other mine workings to the north of the St. Louis Tunnel is currently not known but is judged to be very unlikely, based on available historic mine maps.

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Therefore, the feasibility of reducing or controlling flows and/or contaminants that are contributed by the 145 Raise cannot be fully assessed but is judged to be low.

3.5 HYDRAULIC CONTROLS CONCLUSIONS

The subsurface workings that are known to be safely accessible are the 517 Shaft Access Tunnel and the near portal reach of the Blaine Tunnel. The 517 Shaft Access Tunnel connects to the top collar of the 517 Shaft but does not provide direct access to mine water flowing through the SE Cross-cut. The Blaine Tunnel provides access to the mine water pool that drains to the Humboldt Drift, contributing a small fraction of the overall flow that discharges from the St. Louis Tunnel. Implementation of hydraulic controls at either of these locations is unlikely to substantially reduce volumetric or contaminant loading of the St. Louis Tunnel discharge.

For other areas that contribute to the St. Louis Tunnel discharge (i.e., NW Cross-cut, 145 Raise, and the workings to the south of Silver Creek above the Blaine level), methods for hydraulic control of mine water cannot be adequately evaluated due to lack of information on safe access. Even with safe access, substantial investigations would be needed to determine feasible locations and the likely future success or effects of hydraulic control measures.

Although the existence of major faults is known and infiltration through these features is presumed to occur, evaluations of their accessibility for grouting, their distribution and extent, and the extent to which grouting would reduce water flow to the St. Louis Tunnel was beyond the scope of this investigation. The feasibility of effectively reducing infiltration to the mine workings and reducing flow at the St. Louis Tunnel by this method cannot be evaluated currently.

4.0 SOURCE WATER CONTAMINANT CONTROL

The following sections briefly describe the results of a treatability study conducted in 2012 and 2013 to evaluate the hydraulics, water chemistry, and potential source control measures at the 517 Shaft. The treatability study included geophysical characterization of the 517 Shaft, injection of alkaline solutions into the shaft to precipitate metals in source water from the Blaine-Argentine mine workings, and tracer studies to evaluate the hydraulic characteristics of the mine workings between the shaft and the St. Louis Tunnel. Complete results will be presented in a forthcoming injection test completion report.

4.1 GEOPHYSICAL CHARACTERIZATION OF THE 517 SHAFT

Geophysical characterization of the 517 Shaft was conducted by Layne Christensen Company – Colog Division (Colog) in 2012 and 2013, prior to commencing each of the 2012 and 2013

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injection tests. The goals of these surveys were to determine the hydraulic characteristics of the 517 Shaft; evaluate the geometry and physical conditions of the shaft and the stratification of water chemistry; and provide pre-injection test water quality data. Additionally, the 2013 characterization work documented 517 Shaft conditions during the spring run-off period, when snowmelt and surface water flow rates were anticipated to be at or near the annual peak. This section briefly describes the survey methods and findings. Additional details are provided in the 2012 and 2013 summary reports included as Attachments 4 and 5, respectively.

4.1.1   Methodology

The 517 Shaft characterization work conducted in 2012 included downhole video logging of the shaft, vertical logging of water quality parameters, measurement of vertical flow velocities in the submerged portion of the shaft, and collection of discrete water samples at two depths. This work was performed during the first week of September 2012. Similar characterization efforts were conducted in 2013, with additional measurement of horizontal flow velocities and water quality parameters, collection of water samples at discrete depths throughout the submerged portion of the shaft, and deployment of a sonar system to develop a three-dimensional image of the submerged portion of the shaft, where video quality was limited due to the turbid mine water. All tools and equipment for the geophysical characterization efforts were lowered into the 517 Shaft from a pulley mounted on an A-frame structure above the collar of the 517 Shaft lift-access chamber (see photograph in Attachment 5-2).

Video logs of the 2012 and 2013 shaft surveys are included on digital video discs included with Attachments 4 and 5, respectively.

4.1.2   Physical Conditions

The 517 Shaft is located approximately 220 feet in-by the 517 Shaft Access Tunnel portal (Figure 1 and Attachment 1). Video logging of the 517 Shaft indicated that the shaft is fully timbered and consists of two vertical chambers, each with a cross-sectional area of approximately seven feet by seven feet. One chamber provided lift access to lower levels of the historic mine workings, while the other chamber enclosed a series of ladders and served as a manway. Platforms were constructed within the ladder chamber at approximately eight-foot vertical intervals.

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The total depth of the shaft is approximately 622 feet,[8] and the depth to water was approximately 453 feet during both 2012 and 2013 characterization efforts.[9] Based on these measurements, approximately the lower 170 feet of the 517 Shaft are flooded.

Video and sonar observations indicated that at least four different mine workings levels may intersect the 517 Shaft at various depths. Features at the following distances below the shaft collar were noted:

- 14 feet – observed horizontal tunnel with rail tracks and rail car

- 90 feet – 200 level tunnel intersection observed to the northeast (NE)

- 209 feet – 300 level tunnel intersections observed to the NE and southwest (SW)

- 351 feet – 400 level tunnel intersections observed to the NE and SW

- 452 feet – 500 level tunnel intersections observed to the NE and SW; observed a sheave near the top of the tunnel within the ladder chamber

- 453 feet – surface of pooled mine water

- 464-472 feet – observed collapsed beams and an absence of the ladder chamber, potentially indicating a tunnel intersection

- 494 feet – deepest observation of the ladder chamber; lift guides still visible below this depth

- 503-506 feet – observed collapsed beams; large voids absorbed acoustic signal; potential tunnel intersection

- 523-527 feet – deepest extent of camera and flow meter advancement due to collapsed timbers obstructing the shaft; large voids absorbed acoustic signal; potential tunnel intersection

- 536 feet – deepest extent of sonar advancement due to collapsed timbers obstructing the shaft

- 622 feet – deepest extent of the 517 Shaft

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[8] All 517 Shaft depth measurements are approximate and are provided as measured from the shaft collar at the ground surface of the 517 Shaft Access Tunnel portal.
[9] All depths presented herein are referenced to the shaft collar, as presented in the 2013 Colog report (Attachment 5).

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4.1.3   Water Quality

Vertical profiles of water quality parameters were collected in 2012 and 2013 using the methods and instrumentation described in Attachments 4 and 5. The following notable trends were observed in water quality parameters.

- Fluid temperature generally increased with depth for approximately the first 20 feet below the water surface, indicating that heat is lost from the surface of the pool or that water dripping into the 517 Shaft from above was much colder than mine water pooled within the shaft.

- Water quality parameters in both 2012 and 2013 changed abruptly between the depths of 490 feet and 500 feet and at approximately 523 feet deep. In 2012 (Appendix A in Attachment 4), dissolved oxygen decreased at about 497 feet (corresponding to an apparent outflow from the shaft). Fluid conductivity decreased at 523 feet (corresponding to apparent inflow to the shaft) in the 2012 survey, but increased at a depths between 520 and 525 feet during the 2013 survey (Appendix A in Attachment 5). The conductivity stratification in 2013 may indicate the presence residual alkaline solution that was injected into the shaft during 2012.

- ORP was measured consistently between approximately 100 millivolts (mV) and 200 mV. A slight drop in ORP was noted at a depth of about 497 feet during the 2013 survey, corresponding to an apparent outflow from the shaft.

- pH was generally consistent with depth. In 2012, pH was approximately 5.6 throughout the water column. In 2013, pH ranged between approximately 6.7 and 7.0. The slightly higher pH in 2013 may indicate lingering impacts of the alkaline solution injections during autumn 2012 (Section 4.2).

4.1.4   Flow Observations

Flow measurements, vertical profiling of water quality parameters, and video and sonar observations were compared to identify depths at which mine water may enter or exit the 517 Shaft. Methodology and instrumentation are described in Attachments 4 and 5. The flow measuring devices deployed in 2012 and 2013 were unable to quantify flow rates within the 517 Shaft because the cross-sectional area of the shaft is neither consistent nor well established. However, the flow measurements did indicate general flow directions and relative magnitudes. Differences in flow direction as a function of depth were generally supported by anomalies in the water quality parameter vertical profiles. Flow data are included in Attachment 5.

Both 2012 and 2013 observations indicated that water in the 517 Shaft flows generally upward and out at or near the water surface (453 feet deep), thought to coincide with the St. Louis Tunnel (500) level. Measurements in 2013 further indicated that flow leaving the shaft was

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generally to the northeast, corresponding to the direction in which mine workings connect to the SE cross-cut, as indicated on historic maps (Attachment 1).

In 2013, downward flow was observed within the top foot of the water column in the 517 Shaft, possibly due to mixing caused by water dripping into the pooled mine water from above. Other observed variations in flow velocity (in 2013) and direction (in 2012) may be indicative of water entering and exiting the 517 Shaft at multiple depths below the pool surface, or it may indicate that flow from the 517 Shaft is minimal except during periods of winter snowmelt or heavy precipitation. Vertical flow data from 2012 indicated that water diverged at a depth of approximately 470 feet, indicating that water may enter the shaft at this depth. This depth coincided with collapsed timbers observed between 464 feet and 472 feet.

Water was also observed to converge at a depth of approximately 495 feet, indicating that water may exit the shaft at this depth. This depth coincided with the terminal depth of the ladder chamber, the abrupt change in water quality parameters observed between 490 feet and 500 feet, and a notable decrease in fluid velocity around 490 feet. Below approximately 525 feet, mine water appears to be stagnant or pooled. Therefore, it is not expected that a substantial source of water enters or exits the 517 Shaft from a depth below 525 feet.

4.2   2012 INJECTION TEST

The 2012 treatability study was conducted over 42 days between September and November 2012 to evaluate the effectiveness of chemical addition for increasing alkalinity and pH of mine water in the 517 Shaft, and precipitating metals inside the mine workings in order to reduce the dissolved metals load in water that discharges from the St. Louis Tunnel. A 23.5% potassium carbonate (K_2CO_3) solution was injected below the water surface in the 517 Shaft for the entire test. Starting on day 21, water from Silver Creek was injected at about 25 gpm as carrier water due to low flows through the mine workings. During the final week, a 25% sodium hydroxide (NaOH) solution was injected. Both the Silver Creek water and the NaOH solution were discharged from an injection pipe at the shaft collar.

Injection totals were as follows: 22,700 gallons of K_2CO_3 solution; 330 gallons of NaOH solution; and 626,800 gallons of Silver Creek water. Water quality parameters were continuously monitored throughout the test and water samples were collected periodically from the 517 Shaft and the St. Louis Tunnel portal area (monitoring location DR-3A, located downstream of the portal and upstream of existing monitoring location DR-3; Figure 1-2).

4.2.1   517 Shaft Results

Injection of K_2CO_3 into the 517 Shaft rapidly increased the pH and alkalinity and decreased metals concentrations in mine water pooled within the shaft (Figure 4-1). The pH in the 517 Shaft increased from pH 6.1 to as high as pH 10.7 with injection of K_2CO_3 and as high as pH 11.7 with the injection of K_2CO_3 and NaOH during the final week of the test (Figure 4-1). The total alkalinity increased from approximately 30 mg/L as calcium carbonate ($CaCO_3$) to approximately 3,000 mg/L as $CaCO_3$ with injection of K_2CO_3. Concurrent injection of NaOH and K_2CO_3 resulted in minimal further alkalinity increases (Figure 4-1), although the form of alkalinity shifted from predominately bicarbonate to carbonate. Much of the alkalinity injected as K_2CO_3 was apparently lost to softening mechanisms, primarily the precipitation of calcium as $CaCO_3$. Metals concentrations in the 517 Shaft generally decreased in response to injection (Figure 4-1). Injection of K_2CO_3 decreased many metals concentrations in the 517 Shaft by about 90%, and injection of K_2CO_3 and NaOH decreased many metals concentrations by about 95%. Concentrations of dissolved cadmium, manganese, and zinc in the 517 Shaft were reduced to less than their respective reporting limits by the end of the injection. Metals concentrations partially rebounded within one week after injection stopped.

4.2.2   St. Louis Tunnel Discharge Results

At DR-3A, pH increases were no more than 0.3 standard unit from about pH 6.7 to 7.0 in response to K_2CO_3 and NaOH injection (Figure 4-2), in contrast to an increase of pH 4.6 to 5.6 at the 517 Shaft, due to dilution and neutralization within the flow system between the 517 Shaft and the St. Louis Tunnel discharge. Total alkalinity at DR-3A (in the form of bicarbonate alkalinity only) increased by 22% during the first two weeks of injection, but increased doses of K_2CO_3 and injection of NaOH did not further increase alkalinity at DR-3A (Figure 4-2). Zinc and cadmium concentrations at DR-3A decreased by up to 40%, and manganese concentrations decreased by up to 25%. Concentrations partially rebounded during the post-injection monitoring phase (Figure 4-2). The greatest reductions of metals concentrations at DR-3A occurred during the first two weeks of K_2CO_3 injection; the increased K_2CO_3 dose and later injection of NaOH did not substantially increase metals removal upstream of DR-3A.

These results indicate that injection of K_2CO_3 to the 517 Shaft provided sufficient excess alkalinity to reduce concentrations of zinc, cadmium, manganese, and other metals at the St. Louis Tunnel discharge. The subsequent injection of NaOH was insufficient to further increase the alkalinity and pH or to further decrease metals concentrations at DR-3A. The alkalinity added during K_2CO_3 injection was not sufficient to substantially raise the pH at DR-3A or to precipitate more than 40% of the target metal contaminants in the mine workings between the 517 Shaft and DR-3A. The loss of alkalinity was most likely due to softening mechanisms

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(i.e., precipitation of calcium as $CaCO_3$) and sinking of the dense injection solution in the 517 Shaft. The injection location was more than 45 feet below the water surface due to injection hose stretch, exacerbating the loss of alkalinity to the lower part of the shaft. The injection was suspended before higher injection rates could be tested, due to the onset of winter weather conditions.

4.3   2013 INJECTION TEST

Follow-on injection testing was conducted between June 21 and July 9, 2013, to further evaluate chemical injection to the 517 Shaft as a method for reducing concentrations of metals in the St. Louis Tunnel discharge. In an attempt to provide sufficient alkalinity to treat mine water between the 517 Shaft and the St. Louis Tunnel discharge while minimizing carbonate addition and preventing losses of carbonate alkalinity to softening (i.e., precipitation of $CaCO_3$), as was observed during 2012, 25% NaOH solution was injected below the water surface in the 517 Shaft over 18 days in 2013. Additional tracer testing also was performed.

Approximately 4,180 gallons of 25% NaOH solution (equivalent to about 11,200 pounds of NaOH) and 395,000 gallons of Silver Creek water were injected into the 517 Shaft. Water quality parameters were continuously monitored and water samples were collected periodically from the 517 Shaft and DR-3A. Although the 2013 injection test was planned for a longer duration than the 2012 injection test to allow equilibrium concentrations to be established at DR-3A, the 2013 injection test was stopped after 18 days of injection due to failure of an injection system valve and a resulting release of NaOH solution onto the floor of the 517 Shaft Access Tunnel. The media affected by the NaOH were subsequently neutralized.

4.3.1   517 Shaft Results

Injection of NaOH increased the pH and alkalinity and significantly decreased metals concentrations in the 517 Shaft mine water pool (Figure 4-3). The pH of water in the 517 Shaft increased from pH 6.8 to 8.9 within 20 hours of starting NaOH injection and increased to a peak of pH 12.8 within two weeks of the start of the injection. The addition of Silver Creek water likely improved mixing of NaOH within the shaft, resulting in higher measured pH. Total alkalinity in the 517 Shaft increased from approximately 252 mg/L as $CaCO_3$ to 978 mg/L as $CaCO_3$ after 18 days of injection, and the predominant form of alkalinity shifted from bicarbonate to 53% carbonate alkalinity and 47% hydroxide alkalinity. The alkalinity increase in the 517 Shaft during the 2013 NaOH injection test (Figure 4-3) was considerably less than the alkalinity increase observed during the 2012 injection of K_2CO_3 (Figure 4-1), possibly due to different mixing characteristics during each test. As was observed in 2012, alkalinity and pH decreased gradually during post-injection monitoring (Figure 4-3).

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Metals concentrations and sulfate in the 517 Shaft generally decreased in response to NaOH injection but rebounded after NaOH injection was terminated (Figure 4-3). Based on a comparison of the 517 Shaft sample collected two days prior to the start of the injection (June 19) and the sample collected at the end of the injection (July 9), concentrations of total cadmium, manganese, and zinc decreased by at least 76%, and concentrations of dissolved cadmium, manganese, and zinc decreased by at least 95% (Figure 4-3). Similar results were observed for calcium, but magnesium concentrations decreased to a lesser extent. Sulfate in the 517 Shaft decreased by 94%, possibly due to precipitation with calcium.

4.3.2 St. Louis Tunnel Discharge Results

At DR-3A, pH increased slightly from pH 6.8 pre-injection to a maximum of pH 7.0 at the end of the injection (Figure 4-4). Similar to the 2012 injection test, the small pH change relative to that observed at the 517 Shaft was likely due to neutralization of alkaline chemicals as the alkaline-solution amended mine water flowed through the mine workings between the 517 Shaft and DR-3A. Alkalinity at DR-3A (bicarbonate only) increased by about 24% during injection and continued to increase during the post-injection monitoring period (Figure 4-4). Much of the alkalinity injected into the 517 Shaft as NaOH was apparently lost due to neutralization within the mine workings or precipitation of non-target metals, such as aluminum. Some of the dense NaOH solution likely sank in the shaft due to inadequate mixing at the injection point, which was more than 45 feet below the water surface due to injection hose stretch. Since alkalinity was lost to the bottom of the shaft, there appears to have been an insufficient dose to adequately treat waters entering the system from the NW Cross-cut or the 145 Raise. The post-injection alkalinity increase at DR-3A may have been caused by slow flushing of NaOH from the shaft after injection was terminated.

Despite the limited increase in pH and alkalinity at DR-3A, total cadmium, zinc, and manganese concentrations at DR-3A were decreased by up to 26%, 20%, and 11%, respectively (Figure 4-4). Total iron was reduced by up to 55%, but concentrations of total calcium and total magnesium were reduced by no more than 10%. These results indicate that much of the contaminant loading contributed to the St. Louis Tunnel by the SE Cross-cut was eliminated by injection of NaOH at the 517 Shaft.

4.4 2012-2013 TRACER TEST RESULTS

Tracer testing during the 2012 and 2013 injection tests confirmed that a hydraulic connection exists between the 517 Shaft and the St. Louis Tunnel discharge and provided information about the hydraulic characteristics of the mine workings. The following sections present a brief

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summary of 2012 and 2013 tracer test activities and results; additional results and discussion will be included in the forthcoming injection test completion report.

4.4.1   2012 Tracer Test Results

Lithium chloride solution was continuously injected into the 517 Shaft for the first 12 days of the 2012 injection test, concurrent with the injection of K_2CO_3. During that time, both lithium and chloride increased and slowly approached their expected equilibrium concentrations at DR-3A (Figure 4-5). About 64% of the injected lithium was recovered at DR-3A during the monitoring period, whereas less than 1% of injected chloride was recovered, most likely due to the relatively high chloride detection limit (0.5 mg/L), which prevented quantification of low chloride concentrations early in the tracer test.[10] Lithium that was not recovered may have been stored in the 517 Shaft mine water pool, below the 500 level discharge to the SE Cross-cut and the St. Louis Tunnel.

The tracers injected into the 517 Shaft in 2012 were slow to appear at DR-3A in comparison to a previous tracer test. URS (2012) reported that tracers injected into the 517 Shaft first appeared at DR-3A in about 15 hours, while peak tracer concentrations arrived in 21 to 37 hours. The mean hydraulic residence time (HRT) between the 517 Shaft and DR-3A based on the October 2011 pulse injection tracer test was about 9.3 days, whereas the mean HRT during the 2012 injection test was approximately 10.8 days. In the 2012 continuous injection tracer test, elevated lithium concentrations first were observed about 2 to 3 days after the start of injection, and peak concentrations were observed about 13 days after the start of injection (Figure 4-5). The shorter travel time reported by URS (2012) likely was due to rapid injection of 50,000 gallons of chase water into the 517 Shaft immediately following tracer injection, which would have rapidly flushed the tracer out of the 517 Shaft and into the SE Cross-cut. During the 2012 tracer test, the tracer solution was injected at a slower rate with considerably less volume. Lithium chloride was injected with about 6,900 gallons of K_2CO_3 solution at a maximum flow rate of 0.6 gpm, with no additional chase water.

4.4.2   2013 Tracer Test Results

Sodium was continuously injected as NaOH for the duration of the 2013 injection test, and sodium concentrations were monitored in the 517 Shaft before and after injection (Figure 4-6). Post-injection sodium concentrations in the 517 Shaft decreased exponentially. Reactor modeling of post-injection sodium concentrations in the 517 Shaft indicates that the mean HRT in the shaft is more than 18 days under natural (no injection) flow conditions. These calculations

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[10] The expected chloride concentration was about 2 mg/L (as shown in Figure 4-5), but the method detection limit for chloride was 0.5 mg/L.

assume that the 517 Shaft was a completely mixed reactor with constant volume and clean inflow under post-injection conditions. Under these conditions, the residual sodium would be flushed slowly from the system, and the concentration would decrease over time. The mean HRT of more than 18 days supports other observations that suggest that natural flow through the 517 Shaft and into the SE Cross-cut is limited.

The expected sodium equilibrium concentration at DR-3A was about 75 mg/L, based on the NaOH injection rate, background sodium concentration, and flow rate recorded at DR-3. The highest sodium concentration detected at DR-3A was 38 mg/L on July 9, or about 51% of the expected equilibrium concentration (Figure 4-6). Numerical integration of the DR-3A sodium concentrations and flow rates indicate that only 49% of the injected sodium exited the St. Louis Tunnel portal during the monitoring period (June 21 to September 16). Assuming that sodium is nonreactive within the mine workings, the low sodium recovery indicates that half of the injected sodium remained within the mine workings, possibly due to poor mixing and storage of NaOH in the 517 Shaft, sinking of the dense NaOH solution in the 517 Shaft, or sorption of sodium ions to mineral surfaces within the mine workings. Since sodium did not approach equilibrium at DR-3A, sodium results cannot be used to estimate the mean HRT of the mine workings between the 517 Shaft and DR-3A under the conditions of the 2013 injection test.

4.5   POTENTIAL FOR SLUDGE GENERATION

In-situ chemical precipitation of metals will reduce dissolved concentrations of metals in drainage that discharges from the St. Louis Tunnel and will generate metal precipitate sludge within the mine workings. The settleability of precipitated metals and the potential sludge storage volume within the mine workings are not known; therefore, the quantity of precipitated metals that may be retained within the mine workings is unknown. This section estimates sludge generation rates for two in-situ treatment scenarios: complete treatment of the flow that discharges from the St. Louis Tunnel and treatment of the SE Cross-cut only. These estimates can be used for assessing the potential longevity of underground sludge storage, as well as future requirements for sludge disposal outside the St. Louis Tunnel if underground sludge storage capacity is fully utilized.

The following assumptions were made for these sludge generation estimates:

- Flow at DR-3 is assumed to be 530 gpm, based on a manual flow measurement from June 12, 2013. The flow proportions presented by Anaconda (1982; see Section 2.2) based on 1980 observations are accurate. Thus, the flow from the SE Cross-cut is about 353 gpm (2/3 of the flow at DR-3), and combined flow from the NW Cross-cut and 145 Raise is about 177 gpm.

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- Pre-injection concentrations in samples acquired during 2013 from DR-3 and the 517 Shaft are representative of system baseline conditions. Samples from the 517 Shaft are assumed to represent mine water flowing through the SE Cross-cut.

- Calcium and magnesium will both precipitate after chemical injection, consistent with 2012-2013 injection test observations. Magnesium hydroxide and $CaCO_3$ are included in the sludge generation estimates.

- Other target metals that are assumed to precipitate as hydroxides are iron, cadmium, zinc, aluminum, and copper. Manganese is assumed to precipitate as manganese carbonate. Other metals that are present at lower concentrations are not considered, and sodium, potassium, and lithium are assumed to produce no sludge.

- Treatment efficiency is not considered. An assumption of complete precipitation of the target metals will result in a conservative, worst-case sludge production estimate.

The maximum amount of sludge production would occur when all metals in the discharge from DR-3 are precipitated. This scenario applies to a treatment system constructed at the St. Louis Tunnel outlet and to an in-situ approach that injects sufficient alkaline chemical to precipitate all metals from both the SE and NW Cross-cuts. Based on the contaminant mass discharge rate at DR-3 (product of flow rate and concentration), about 1,800 pounds per day (lbs/day) of metals are discharged, but nearly 4,500 lbs/day of sludge would be generated (Table 4-1). Higher flow rates would yield proportionately higher sludge generation rates, assuming concentrations of metals and flow proportions remained constant. The estimated sludge mass consists mostly of $CaCO_3$ (89% of the sludge mass) and magnesium hydroxide (7% of the sludge mass).[11] Less than 2% of the estimated sludge mass would be from removal of the main metals of interest (cadmium, manganese, and zinc). Precipitated solids could be settled from the St. Louis Tunnel effluent, if insufficient sludge storage volume is available in the mine workings.

A separate scenario assumes that sludge is generated by in-situ treatment of only the SE Cross-cut flow (similar to the 2012-2013 injection tests), while flow from the NW Cross-cut remains untreated. The flow proportions corresponding to the 1980 Anaconda observations (Section 2.2) are assumed, and the SE Cross-cut is assumed to have metals concentrations equal to the 517 Shaft sample collected on June 19, 2013. At a DR-3 flow rate of 530 gpm, approximately 1,500 lbs/day of metals would be removed, corresponding to about 3,600 lbs/day of sludge production (Table 4-1). More than 90% of this estimated sludge production is from precipitation of calcium. Under this scenario ("517 Shaft Treatment Scenario" in Table 4-1), the zinc concentration and loading at DR-3 would be reduced by about 46%, cadmium would be

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[11] Actual sludge mass would be dependent on final pH achieved within the system. These estimates assume a worst-case sludge production scenario in which all metals precipitate and no precipitates are re-dissolved. In reality, actual sludge production would depend on many geochemical interactions.

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reduced by 27%, and manganese would be reduced by 42%. Other metals would be reduced by 5% to 85% by eliminating metals from SE Cross-cut.

Based on these calculations, in-situ precipitation of metals likely would result in substantial sludge generation rates, and much of the generated sludge would consist of calcium and magnesium solids. The available sludge storage volume within the mine workings is currently not known but is assumed to be finite.[12] Development of methods to avoid softening mechanisms and prevent precipitation of non-target metals could reduce sludge generation rates, but in-situ chemical precipitation most likely would require a supplemental solids removal process to eventually be placed downstream of DR-3 for effective solids capture.

Further analysis of potential sludge generation rates under different in-situ treatment scenarios will be presented in the forthcoming injection test completion report.

4.6   INJECTION TEST CONCLUSIONS

As discussed in Sections 4.2 and 4.3, the 2012 and 2013 injection tests provided useful information about in-situ chemical precipitation. In response to injection of alkaline solutions, total alkalinity and pH increased in the 517 Shaft. Injection of K_2CO_3 reduced metals concentrations in the 517 Shaft by about 90%, concurrent injection of NaOH and K_2CO_3 reduced metals concentrations by about 95%, and injection of NaOH alone (during the 2013 test) reduced total metals by at least 76% and dissolved metals by at least 95%. At DR-3A, metals concentrations were reduced by up to 40% during the 2012 injection of K_2CO_3 and by as much as 26% during the 2013 injection of NaOH. During both tests, total alkalinity in DR-3A samples increased no more than 24%, and pH increases were minimal. Based on historical observations of flows and zinc loadings (Section 2.3), most of the contaminant load from the SE Cross-cut was treated during both injection tests, and some of the contaminant load from the NW Cross-cut may have been treated during the 2012 test due to higher inputs of alkalinity. Metals concentrations in the 517 Shaft and at DR-3A partially rebounded after injections were terminated.

During both tests, much of the injected chemical did not treat target metals due to non-optimal chemical delivery (i.e., poor mixing and loss of chemical within the 517 Shaft), neutralization within the mine workings, and precipitation of non-target metals (i.e., calcium, magnesium, and

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[12] AECOM (2013b) estimated that the available volume of the mine workings is about 600,000 cubic feet from the St. Louis Tunnel portal area up to, but not including, workings at or above the Blaine level. This estimate includes the St. Louis Tunnel, cross-cuts, 517 Shaft, and Blaine-Argentine 500 through 200 levels open haulageway areas. This estimate does not include stoped areas that likely amount to substantially greater volume of openings; these openings likely are not where settling of precipitates would occur efficiently.

aluminum). As indicated by poor recovery of tracer ions in both tests, some of the dense alkaline solution likely sank into the pooled water in the 517 Shaft before mixing. The 517 Shaft is a non-ideal injection location because of the large water volume below the injection point and the location of the shaft at the end of a short, upward-sloping drift approximately 150 feet off the main 500 level workings (Figure 3 of Attachment 1). These factors, in addition to injection about 30 feet deeper in the 517 Shaft water column than intended due to stretching of the injection hose, prevented alkaline solutions from directly treating mine water in the SE Cross-cut and resulted in an insufficient dose to completely treat water from both the SE and NW Cross-cuts.

In summary, injection of K_2CO_3 to the 517 Shaft reduced concentrations of zinc, cadmium, manganese, and other metals at the St. Louis Tunnel discharge by increasing pH and providing sufficient alkalinity for in-situ precipitation at the 517 Shaft and in the SE Cross-cut. Additional details of the 2012-2013 injection tests will be presented in a forthcoming injection test completion report.

If other water treatment alternatives that currently are being evaluated for the site do not provide sufficient treatment for the St. Louis Tunnel discharge, in-situ chemical precipitation could be developed further. Future investigation and improvements to the injection approach potentially could include:

- Other injection location(s) could be considered for treating the SE Cross-cut. The 517 Shaft is accessible under current conditions but has limited flow due to its location on a drift off the SE Cross-cut (Figure 3 of Attachment 1). Injection of carrier water probably would be required to effectively mix chemicals into the SE Cross-cut. The shaft also has a water column that extends for about 170 feet below the SE Cross-cut level, allowing some of the injected chemical to sink or treat non-target mine water below the injection point, regardless of injection depth. Direct injection into the SE Cross-cut could provide more efficient treatment of mine water, although this would require installation of a boring in the vicinity of the Argentine Shaft or other location above the SE Cross-cut (Figure 3 of Attachment 1).

- Other injection location(s) could be considered to treat water from the NW Cross-cut. Historic observations indicate that the NW Cross-cut contributes about 25% of flow and possibly more than 60% of zinc loading at the St. Louis Tunnel discharge. Injection locations other than the 517 Shaft, such as unexplored areas north of the St. Louis Tunnel, could be evaluated to avoid neutralization of injected chemicals during transport in the SE Cross-cut and to more directly treat the NW Cross-cut.

- Injection and tracer testing could be conducted for a longer duration to allow the system to approach steady state conditions. Longer-term testing would allow evaluation of this treatment approach under different seasonal conditions and would provide better geochemical and hydraulic characterization of the system. Additional testing would generate information that would allow prediction of effluent

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concentrations and sludge production, while allowing a determination of the sustainability of this approach.

- Other chemical injection strategies could be considered. Continuous injection of K_2CO_3 and NaOH solutions effectively increased pH and alkalinity and decreased metals concentrations, but continuous injection is relatively expensive and logistically challenging. Periodic dosing with a solid alkalinity source (e.g., soda ash briquettes) could be considered as a less expensive and relatively low maintenance method for implementing in-situ chemical precipitation, particularly if the alkalinity source could be placed directly into one of the cross-cuts. This method could be implemented periodically during periods of peak metals discharge (i.e., high flow and/or high metals concentrations).

- If treatment in the 517 Shaft is conducted in the future, then the injection system design should be improved to eliminate injection hose stretch, optimize injection location, and improve mixing of injected chemicals into the water to be treated.

5.0   CONCLUSIONS AND RECOMMENDATIONS

The following sections present conclusions and recommendations for hydraulic and contaminant control methods, based on currently available information.

5.1   HYDRAULIC CONTROL METHODS

Based on available information on flow contributions to the St. Louis Tunnel, most of the flow is contributed by the SE Cross-cut, with estimates ranging from 39% to 82% of the total flow at the St. Louis Tunnel portal. The NW Cross-cut is believed to contribute 12% to 25% of the total flow, and the 145 Raise is thought to be a minor contributor (less than 10%). Inflow to the St. Louis Tunnel through fractures and/or drill holes between the portal and the tunnel intersection may contribute some of the flow discharging from the portal. Measurable flows from the accessible part of the Blaine Tunnel are a minor contributor to the overall flow at DR-3. Most areas of the subsurface workings are not accessible currently, so no recent flow measurement or other data exists to verify flow contributions from different parts of the mine workings.

Due to a lack of recent information on flows through the workings, there is little information with which to evaluate hydraulic controls. Based on currently available information, there are no readily accessible locations to install bulkheads or plugs to control flows. Hydraulic control measures in the accessible part of the Blaine Tunnel would not reduce the hydraulic or contaminant loading at the St. Louis Tunnel significantly. If hydraulic controls could be installed safely, the potential effects are currently unknown. As water is stored behind the control structure, the increased hydraulic head throughout the upgradient portions of the mine workings could lead to unforeseen consequences, such as flow along alternate underground flow paths and eventual uncontrolled leakage from the mine workings, with impacts to surface waters or

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shallow alluvial groundwater. Although the existence of major faults is known and infiltration through these features is presumed to occur, evaluations of their accessibility for grouting, their distribution and extent, and the extent to which grouting would reduce water flow to the St. Louis Tunnel was beyond the scope of this investigation.

5.2   CONTAMINANT CONTROL METHODS

Injection of alkaline solutions to the 517 Shaft increased total alkalinity and pH and reduced metals concentrations in the 517 Shaft. Metals concentrations at the St. Louis Tunnel portal were reduced by up to 40% during the 2012 injection of K_2CO_3 and by as much as 26% during the 2013 injection of NaOH, with minor pH increases. Most of the contaminant load from the SE Cross-cut was treated during both injection tests, and some of the contaminant load from the NW Cross-cut may have been treated during the 2012 test due to higher inputs of alkalinity.

In-situ chemical precipitation could be improved by altering the injection location (if possible) to directly treat the main flows and by increasing mixing energy at the injection point. These improvements would allow more effective injection to directly treat a larger proportion of the mine water from the SE and NW Cross-cuts and could avoid excessive neutralization of injected chemicals during transport within the mine workings. Other injection location(s) could be considered for treating water from the NW Cross-cut, which appears to contribute the highest contaminant mass fraction to the St. Louis Tunnel. Other chemical injection strategies, such as campaign treatment, could be considered for in-situ treatment of flows from the SE or NW Cross-cuts during periods with the highest rates of metals discharge.

Although in-situ chemical precipitation can partially reduce effluent concentrations at the St. Louis Tunnel portal, sludge generation rates would be substantial, particularly due to precipitation of non-target metals, such as calcium and magnesium. Methods for reducing the precipitation of non-target metals may improve treatment efficiency while minimizing solids generation. Since the finite sludge storage volume within the mine workings will eventually be exceeded, in-situ chemical precipitation will provide, at best, a partial or interim solution for reducing the rate of metals discharge from the St. Louis Tunnel.

No further testing of in-situ chemical treatment is recommended at this time. If other water treatment alternatives that currently are being evaluated for the site do not provide sufficient treatment for the St. Louis Tunnel discharge, in-situ chemical precipitation potentially could be revisited. Future field investigations and further development of this treatment method could include the items described in Section 4.6 to better understand the flow and contaminant contributions from different parts of the mine workings and improve the injection location and chemical delivery methods.

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TABLE 2-1
HISTORICAL FLOW PROPORTIONS AND ANALYTICAL
RESULTS FOR INPUTS TO THE ST. LOUIS TUNNEL
EVALUATION OF SOURCE WATER CONTROLS
Rico-Argentine Mine Site
Dolores County, Colorado

Parameter[1]	SE Cross-cut[2]	NW Cross-cut[3]	145 Raise[4]	St. Louis Portal[5]	St. Louis Adit Discharge[6]
Estimated Flow Proportion[7]	67%	25%	8%	100%	*not reported*
pH[8]	1.7	2.0	1.8	1.8	7.0
Fluoride (mg/L)	2.7	18	1.7	4.3	5.8
Sulfate (mg/L)	544	1,070	505	562	620
Total Zinc (mg/L)	2.62	27	0.50	5.2	5.00
Total Iron (mg/L)	3.7	102	5.6	16.2	12.8
Total Cadmium (mg/L)	0.009	0.107	<0.001	0.022	0.029
Total Lead (mg/L)	<0.05	0.13	<0.05	<0.05	<0.05
Mercury (mg/L)	0.00005	0.00005	0.00007	0.00005	0.00005

Notes
1. Results reported by Anaconda (1982) and Commercial Testing & Engineering Co. (1980) for samples and observations dated August 18, 1980.
2. Sample location described by Anaconda (1980) as "St. Louis Tunnel Discharge from the SE Drift."
3. Sample location described by Anaconda (1980) as "St. Louis Tunnel Discharge from the North Drift."
4. Sample location described by Anaconda (1980) as "St. Louis Tunnel Discharge from the 145 Raise Area."
5. Sample location described by Anaconda (1980) as "Total Discharge - St. Louis Portal."
6. Sample location described by Anaconda (1980) as "St. Louis adit discharge."
7. Flow proportions are "estimated portion of total flow" reported by Anaconda (1982).
8. All pH values reported by Commercial Testing & Engineering Co. (1980) were flagged with the following footnote, with the exception of the St. Louis Adit Discharge sample pH: "pH value may be low due to the possibility that the sample may have been preserved w/ acid."

Abbreviations
< = analyzed but not detected above the method reporting limit shown
mg/L = milligram per liter
NW = northwest
SE = southeast

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TABLE 2-2
OPTIMIZATION OF ST. LOUIS TUNNEL FLOW PROPORTIONS
EVALUATION OF SOURCE WATER CONTROLS
Rico-Argentine Mine Site
Dolores County, Colorado

Parameter	Reported Flow Estimates and Analytical Results[1]				Projected SLT Discharge[2]	Ratio of Projected to Reported[3]	Optimized SLT Discharge[4]	Ratio of Optimized to Reported[4]	Relative Error[4]	Normalized Fractional Mass Loading[5]		
	SE Cross-cut	NW Cross-cut	145 Raise	SLT Discharge						SE Cross-cut	NW Cross-cut	145 Raise
Flow Fraction	67%	25%	8%	100%	100%	1.00	100%	1.00	0	82%	12%	6%
Fluoride (mg/L)	2.7	18	1.7	4.3	6.4	1.50	4.5	1.05	0.0022	49%	49%	2%
Sulfate (mg/L)	544	1070	505	562	670	1.19	610	1.09	0.0073	73%	22%	5%
Zinc, total (mg/L)	2.62	27	0.5	5.2	8.5	1.64	5.5	1.05	0.0025	39%	60%	1%
Iron, total (mg/L)	3.7	102	5.6	16.2	28	1.76	16	0.98	0.0006	19%	79%	2%
Cadmium, total (mg/L)	0.009	0.107	<0.001	0.022	0.033	1.49	0.020	0.93	0.0054	36%	64%	--
Lead, total (mg/L)	<0.05	0.13	<0.05	<0.05	--	--	--	--	--	--	--	--
Mercury (mg/L)	0.00005	0.00005	0.00007	0.00005	0.00005	1.03	0.00005	1.02	0.0006	80%	12%	8%
Optimized Flow Fraction[4]	**82%**	**12%**	**6%**					**Sum of Squared Errors:**	0.019			

Notes

1. Flow fractions and concentrations reported by Anaconda (1982) memorandum.
2. Concentrations calculated as the sum of flow fractions for tunnels contributing to the St. Louis Tunnel discharge multiplied with the reported concentrations.
3. Ratios calculated as the sum of mass inputs from the three contributing tunnels divided by mass output at the St. Louis Tunnel discharge. Ratios greater than 1.00 imply that either more mass is contributed by intersecting tunnels than is discharging from the St. Louis Tunnel or reported flow fractions are not accurate.
4. Flow fractions were optimized in order to approximate the St. Louis Tunnel discharge concentrations (based on mass inputs from the three contributing tunnels), targeting ratios of 1.00 for optimized to actual St. Louis Tunnel discharge concentrations and minimizing relative error.
5. Calculated as the mass input from each contributing tunnel, based on the optimized flow fraction, divided by the reported SLT discharge concentration.

Abbreviations

-- = not calculated due to lack of detected concentrations
% = percent
< = analyzed but not detected above the method reporting limit shown
mg/L = milligram per liter
SLT = St. Louis Tunnel

References

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TABLE 2-3
ANALYTICAL AND FIELD MONITORING RESULTS
2012-2013 BLAINE TUNNEL AND SELECTED DR-3 WATER SAMPLES
EVALUATION OF SOURCE WATER CONTROLS
Rico-Argentine Mine Site
Dolores County, Colorado

Sample:		Baseline, cofferdam	BLAINEIBF121004	BLAINEOBF121004	BLAINEIBF121016	BLAINEOBF121016	BLAINEIBF121031	BLAINEOBF121031	BLAINEIBF121114	BLAINEOBF121114	BLAINEIBF130430	BLAINEOBF130430
Date:		9/5/2012 17:47	10/4/2012 9:49	10/4/2012 9:39	10/16/2012 14:55	10/16/2012 14:50	10/31/2012 13:00	10/31/2012 12:55	11/14/2012 15:10	11/14/2012 15:05	04/30/2013 10:10	04/30/2013 10:00
Parameter	Units	Result	Result	Result	Result	Result	Result	Result	Result	Result	Result	Result
Metals												
Aluminum, Total	µg/L	268,000	NA	NA	NA	NA	NA	NA	NA	NA	199,000	248,000
Aluminum, Dissolved	µg/L	279,000	NA	NA	NA	NA	NA	NA	NA	NA	199,000	257,000
Antimony, Total	µg/L	<2.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Antimony, Dissolved	µg/L	<50.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Arsenic, Total	µg/L	341	<200	3,060	44.3J	3,620	<1,000	4,890	30.0J	5,520	17.1 J	2,550
Arsenic, Dissolved	µg/L	364	62.8J	2,920	39.5J	3,460	<1,000	4,940	29.3J	5,410	19.5 J	2,630
Barium, Total	µg/L	<1.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Barium, Dissolved	µg/L	<30.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Beryllium, Total	µg/L	27.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Beryllium, Dissolved	µg/L	27.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cadmium, Total	µg/L	1,090	1,320	3,170	1,420	3,390	1,500	4,480	1,510	4,260	1,240	2,830
Cadmium, Dissolved	µg/L	1,540	1,320	2,950	1,420	3,350	1,520	4,530	1,520	4,180	1,220	2,860
Calcium, Total	µg/L	402,000	369,000	431,000	369,000	381,000	389,000	458,000	388,000	414,000	403,000	414,000
Calcium, Dissolved	µg/L	423,000	365,000	432,000	370,000	409,000	380,000	439,000	409,000	428,000	404,000	429,000
Chromium, Total	µg/L	233	221	294	230	240	212J	220J	154	268	171	173
Chromium, Dissolved	µg/L	238	267	295	228	232	232	186J	272J	150	265	169	185
Cobalt, Total	µg/L	237	235	495	236	452	235J	580J	196	528	170	290
Cobalt, Dissolved	µg/L	259	283	466	239	433	219J	576J	198	512	174	299
Copper, Total	µg/L	26,500	26,800	36,000	25,700	34,600	27,200	42,700	17,300	38,800	17,100	24,000
Copper, Dissolved	µg/L	26,600	26,700	33,700	25,500	32,700	26,600	43,900	16,600	37,800	17,600	24,800
Hardness, Total	mg/L	2,010	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Iron, Total	µg/L	1,870,000	1,600,000	2,910,000	1,550,000	2,740,000	1,690,000	4,280,000	1,130,000	3,890,000	1,020,000	2,180,000
Iron, Dissolved	µg/L	1,890,000	1,580,000	2,900,000	1,520,000	2,880,000	1,630,000	4,040,000	1,140,000	3,840,000	1,010,000	2,250,000
Lead, Total	µg/L	202	235	869	226	852	388J	1,080	400	1,030	200	598
Lead, Dissolved	µg/L	244	270	916	225	829	389J	1,110	412	1,010	197	608
Lithium, Total	µg/L	383	NA	NA	NA	NA	NA	NA	NA	NA	247	317
Lithium, Dissolved	µg/L	350	284	369	262	362	285	480	288	450	249	338
Magnesium, Total	µg/L	245,000	215,000	249,000	223,000	235,000	222,000	287,000	231,000	270,000	213,000	228,000
Magnesium, Dissolved	µg/L	246,000	213,000	243,000	221,000	258,000	227,000	284,000	232,000	269,000	211,000	234,000
Manganese, Total	µg/L	113,000	112,000	172,000	114,000	220,000	112,000	216,000	112,000	212,000	91,400	129,000
Manganese, Dissolved	µg/L	107,000	108,000	162,000	115,000	214,000	513J	222,000	113,000	211,000	91,400	132,000
Mercury	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.20	<0.20
Mercury, Dissolved	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.20	<0.20
Molybdenum, Total	µg/L	9.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Molybdenum, Dissolved	µg/L	<50.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nickel, Total	µg/L	398	430	574	426	530	513 J	644J	356	555	328	370
Nickel, Dissolved	µg/L	440	449	551	427	512	397 J	659J	360	542	342	376
Potassium, Total	µg/L	10,500	6,760J	<10,000	6,580	<5000	7,180	<2500	5,760	721J	563 J	<5000
Potassium, Dissolved	µg/L	11,300	5,980J	<10,000	7,350	1330J	7,980	<2500	5,270	1280J	769 J	519 J
Selenium, Total	µg/L	57.7	<200	<200	<100	49.5J	<1000	<1000	<100	64.5J	<100	<100
Selenium, Dissolved	µg/L	39.9	<200	<200	<100	45.1J	<1000	<1000	<100	60.4J	<100	<100
Silica, Total	µg/L	109,000	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Silica, Dissolved	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Silver, Total	µg/L	<2.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Silver, Dissolved	µg/L	<50.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

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TABLE 2-3
ANALYTICAL AND FIELD MONITORING RESULTS
2012-2013 BLAINE TUNNEL AND SELECTED DR-3 WATER SAMPLES
EVALUATION OF SOURCE WATER CONTROLS
Rico-Argentine Mine Site
Dolores County, Colorado

Sample:		Baseline, cofferdam	BLAINEIBF121004	BLAINEOBF121004	BLAINEIBF121016	BLAINEOBF121016	BLAINEIBF121031	BLAINEOBF121031	BLAINEIBF121114	BLAINEOBF121114	BLAINEIBF130430	BLAINEOBF130430
Date:		9/5/2012 17:47	10/4/2012 9:49	10/4/2012 9:39	10/16/2012 14:55	10/16/2012 14:50	10/31/2012 13:00	10/31/2012 12:55	11/14/2012 15:10	11/14/2012 15:05	04/30/2013 10:10	04/30/2013 10:00
Parameter	**Units**	**Result**	**Result**	**Result**	**Result**	**Result**	**Result**	**Result**	**Result**	**Result**	**Result**	**Result**
Sodium, Total	µg/L	6,580	5420J	20,400	5,500	21,700	5,960	26,300	5,320	29,100	4390 J	12,200
Sodium, Dissolved	µg/L	6,940	5520J	19,700	5,330	23,700	34,400	25,900	4340J	28,000	4450 J	12,800
Thallium, Total	µg/L	2.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Thallium, Dissolved	µg/L	<10.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Vanadium, Total	µg/L	334	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Vanadium, Dissolved	µg/L	342	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Zinc, Total	µg/L	228,000	202,000	479,000	216,000	575,000	220,000	623,000	266,000	644,000	183,000	444,000
Zinc, Dissolved	µg/L	226,000	199,000	451,000	217,000	555,000	NA	637,000	270,000	632,000	182,000	436,000
General Water Chemistry and Anions												
Alkalinity, Bicarbonate	mg/L as CaCO$_3$	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	261	<20.0	<20.0	<20.0
Alkalinity, Carbonate	mg/L as CaCO$_3$	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0
Alkalinity, Hydroxide	mg/L as CaCO$_3$	NA	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0
Alkalinity, Total	mg/L as CaCO$_3$	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	261	<20.0	<20.0	<20.0
Total Dissolved Solids	mg/L	2,740	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total Suspended Solids	mg/L	7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sulfide, Total	mg/L	<0.05	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Bromide	mg/L	<1.0	<1.0	<1.0	1.2	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Chloride	mg/L	3.2	1.3	2.0	4.1	2.2	2.2	9.7	1.2	5.8	2.3	<1.0
Fluoride	mg/L	77.1	63.6	47.5	60.2	42.8	53.3	46.3	47.7	50.0	42.3	33.5
Sulfate	mg/L	59,500	13,500	23,400	26,100	27,700	222,000	40,400	23,400	72,400	15,800	23,500
Nitrogen, Nitrate	mg/L	<0.50	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total Organic Carbon	mg/L	4.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Field Monitoring Parameters												
pH	standard units	2.2	2.39	2.14	2.58	2.15	2.41	2.2	2.47	2.03	2.53	2.05
Temperature	˚C	13.57	9.58	10.7	7.38	7.62	10.75	9.2	3.11	0.46	14.19	10.8
Conductivity	µS/cm	7,703	5,237	8,071	4,975	7,851	5,435	9,657	3,921	7,120	6,010	10,033
Dissolved Oxygen	mg/L	0.83	11.57	10.03	NM	NA	8.21	3.91	9.26	7.4	1.46	1.17
Oxidation Reduction Potential	mV	449.8	285.7	303.5	386	398	381.8	395.4	303.6	301.2	491.1	504

Notes

1. DR-3 data provided by Anderson Engineering Company. Only DR-3 data used to perform mass loading calculations was included herein.

2. Preliminary data set.

Abbreviations:

˚C = degrees Celsius

< = analyzed but not detected above the method reporting limit shown

CaCO$_3$ = calcium carbonate

J = result is above method detection limit but below reporting limit

mg/L = milligram per liter

mV = millivolt

NA = not analyzed

µg/L = microgram per liter

µS/cm = microSiemen per centimeter

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TABLE 2-3
ANALYTICAL AND FIELD MONITORING RESULTS
2012-2013 BLAINE TUNNEL AND SELECTED DR-3 WATER SAMPLES
EVALUATION OF SOURCE WATER CONTROLS
Rico-Argentine Mine Site
Dolores County, Colorado

Parameter	Units	Sample: BLAINEIBF Date: 5/17/2013 14:50 Result	BLAINEOBF SEEP 5/17/2013 14:55 Result	BLAINEIBF TRANSDUCER 5/17/2013 15:00 Result	BLAINEIBF130619 6/19/2013 Result	BLAINEOBF130619 6/19/2013 Result	BLAINEIBF130709 7/9/2013 Result	BLAINEOBF130709 7/9/2013 Result	BLAINEIBF130821 8/21/2013 Result	BLAINEOBF130821 8/21/2013 Result	BLAINEIBF130924 9/24/2013 Result	BLAINEOBF130924 9/24/2013 Result
Metals												
Aluminum, Total	µg/L	NA	NA	NA	280,000	322,000	258,000	255,000	235,000	227,000	241,000	257,000
Aluminum, Dissolved	µg/L	NA	NA	NA	256,000	301,000	255,000	251,000	234,000	229,000	249,000	276,000
Antimony, Total	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Antimony, Dissolved	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Arsenic, Total	µg/L	NA	NA	NA	35.4	648	38.6	608	41.7	704	47.9J	1,230
Arsenic, Dissolved	µg/L	NA	NA	NA	34.8	597	39.5	608	40.8	679	51.5J	1,690
Barium, Total	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Barium, Dissolved	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Beryllium, Total	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Beryllium, Dissolved	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cadmium, Total	µg/L	NA	NA	NA	1,530	1,890	1,320	1,610	1,570	1,780	1,400	1,800
Cadmium, Dissolved	µg/L	NA	NA	NA	1,480	2,010	1,340	1,610	1,490	1,740	1,370	2,220
Calcium, Total	µg/L	NA	NA	NA	387,000	408,000	379,000	388,000	357,000	350,000	387,000	401,000
Calcium, Dissolved	µg/L	NA	NA	NA	401,000	427,000	373,000	379,000	358,000	350,000	390,000	399,000
Chromium, Total	µg/L	NA	NA	NA	183	252	216	211	227	221	224	235
Chromium, Dissolved	µg/L	NA	NA	NA	177	196	223	212	207	213	214	242
Cobalt, Total	µg/L	NA	NA	NA	181	288	220	246	238	258	263	300
Cobalt, Dissolved	µg/L	NA	NA	NA	174	212	226	248	215	239	258	346
Copper, Total	µg/L	NA	NA	NA	26,600	29,200	26,000	26,800	23,300	23,700	26,400	28,900
Copper, Dissolved	µg/L	NA	NA	NA	26,600	30,900	25,200	25,000	21,200	22,600	25,800	30,200
Hardness, Total	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Iron, Total	µg/L	NA	NA	NA	1,590,000	2,010,000	1,490,000	1,640,000	1,260,000	1,420,000	1,440,000	1,920,000
Iron, Dissolved	µg/L	NA	NA	NA	1,830,000	2,400,000	1,460,000	1,600,000	1,330,000	1,420,000	1,470,000	2,240,000
Lead, Total	µg/L	NA	NA	NA	184	218	163	201	168	240	219	1,820
Lead, Dissolved	µg/L	NA	NA	NA	176	215	164	201	163	235	214	432
Lithium, Total	µg/L	NA	NA	NA	345	389	288	302	271	261	268	304
Lithium, Dissolved	µg/L	NA	NA	NA	273	328	286	288	265	271	275	358
Magnesium, Total	µg/L	NA	NA	NA	254,000	259,000	221,000	220,000	200,000	201,000	192,000	199,000
Magnesium, Dissolved	µg/L	NA	NA	NA	244,000	262,000	219,000	215,000	197,000	197,000	189,000	212,000
Manganese, Total	µg/L	NA	NA	NA	101,000	114,000	97,000	105,000	102,000	104,000	99,200	106,000
Manganese, Dissolved	µg/L	NA	NA	NA	100,000	119,000	97,800	103,000	98,000	106,000	95,000	115,000
Mercury	µg/L	NA	NA	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.24
Mercury, Dissolved	µg/L	NA	NA	NA	<0.2	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Molybdenum, Total	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Molybdenum, Dissolved	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nickel, Total	µg/L	NA	NA	NA	298	395	374	378	399	402	444	460
Nickel, Dissolved	µg/L	NA	NA	NA	289	316	388	380	362	371	418	440
Potassium, Total	µg/L	NA	NA	NA	4640J	3700J	3,320	2,690	2,620	2,010	10,700	10,500
Potassium, Dissolved	µg/L	NA	NA	NA	3,940	3,320	3,200	2,580	2,680	2,020	11,600	9,320
Selenium, Total	µg/L	NA	NA	NA	21.8	32.2J	22.4	29.4	26.9	37	25.0J	32.9J
Selenium, Dissolved	µg/L	NA	NA	NA	20	29.1	23.8	29.6	29.5	33.7	21.7J	30.5J
Silica, Total	µg/L	NA	NA	NA	44,700	52,000	42,500	43,800	41,400	41,300	43,200	47,400
Silica, Dissolved	µg/L	NA	NA	NA	43,900	52,400	41,600	42,600	40,600	41,000	44,200	48,800
Silver, Total	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Silver, Dissolved	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

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TABLE 2-3
ANALYTICAL AND FIELD MONITORING RESULTS
2012-2013 BLAINE TUNNEL AND SELECTED DR-3 WATER SAMPLES
EVALUATION OF SOURCE WATER CONTROLS
Rico-Argentine Mine Site
Dolores County, Colorado

Sample:		BLAINEIBF	BLAINEOBF SEEP	BLAINEIBF TRANSDUCER	BLAINEIBF130619	BLAINEOBF130619	BLAINEIBF130709	BLAINEOBF130709	BLAINEIBF130821	BLAINEOBF130821	BLAINEIBF130924	BLAINEOBF130924
Date:		5/17/2013 14:50	5/17/2013 14:55	5/17/2013 15:00	6/19/2013	6/19/2013	7/9/2013	7/9/2013	8/21/2013	8/21/2013	9/24/2013	9/24/2013
Parameter	**Units**	**Result**	**Result**	**Result**	**Result**	**Result**	**Result**	**Result**	**Result**	**Result**	**Result**	**Result**
Sodium, Total	µg/L	NA	NA	NA	4910J	6,590	4,270	8,720	4,120	4,490	4,340	4,710
Sodium, Dissolved	µg/L	NA	NA	NA	4400J	6,360	4,140	8,550	4,130	4,550	4,550	4,930
Thallium, Total	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Thallium, Dissolved	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Vanadium, Total	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Vanadium, Dissolved	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Zinc, Total	µg/L	NA	NA	NA	233,000	289,000	197,000	231,000	177,000	198,000	184,000	226,000
Zinc, Dissolved	µg/L	NA	NA	NA	226,000	288,000	200,000	231,000	174,000	196,000	177,000	293,000
General Water Chemistry and Anions												
Alkalinity, Bicarbonate	mg/L as CaCO$_3$	NA	NA	NA	<20	<20	<40	<40	<20	<20	<20	<20
Alkalinity, Carbonate	mg/L as CaCO$_3$	NA	NA	NA	<20	<20	<40	<40	<20	<20	<20	<20
Alkalinity, Hydroxide	mg/L as CaCO$_3$	NA	NA	NA	<20	<20	<40	<40	<20	<20	<20	<20
Alkalinity, Total	mg/L as CaCO$_3$	NA	NA	NA	<20	<20	<40	<40	<20	<20	<20	<20
Total Dissolved Solids	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total Suspended Solids	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sulfide, Total	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Bromide	mg/L	NA	NA	NA	<1	<1	<1	<1	<1	<1	<1	<1
Chloride	mg/L	NA	NA	NA	2	<1	1.8	2.5	1.4	1.6	1.9	0.70J
Fluoride	mg/L	NA	NA	NA	81.9	77.8	92.5	85.8	110	59.5	77.3	72.6
Sulfate	mg/L	NA	NA	NA	23,100	20,600	36,200	18,500	11,700	24,400	11,000	28,900
Nitrogen, Nitrate	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total Organic Carbon	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Field Monitoring Parameters												
pH	standard units	2.28	1.87	1.85	2.4	2.3	2.42	2.34	2.47	2.37	2.34	2.20
Temperature	˚C	9.65	5.81	5.25	15.36	10.34	14.32	14.99	10.61	12.54	10.81	10.78
Conductivity	µS/cm	7,706	12,587	12,657	7,443	8,542	7,040	7,466	6,708	7,308	7,163	9,060
Dissolved Oxygen	mg/L	1.75	1.89	1.68	3.02	3.67	3.85	2.96	3.08	4.33	5.91	6.58
Oxidation Reduction Potential	mV	468.5	485.6	485.4	468	469	447.9	425.1	489.7	498	469.2	475.7

Notes

1. DR-3 data provided by Anderson Engineering Company. Only DR-3 data used to perform mass loading calculations was included herein.

2. Preliminary data set.

Abbreviations:

˚C = degrees Celsius

< = analyzed but not detected above the method reporting limit shown

CaCO$_3$ = calcium carbonate

J = result is above method detection limit but below reporting limit

mg/L = milligram per liter

mV = millivolt

NA = not analyzed

µg/L = microgram per liter

µS/cm = microSiemen per centimeter

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TABLE 2-3
ANALYTICAL AND FIELD MONITORING RESULTS
2012-2013 BLAINE TUNNEL AND SELECTED DR-3 WATER SAMPLES
EVALUATION OF SOURCE WATER CONTROLS
Rico-Argentine Mine Site
Dolores County, Colorado

Parameter	Units	Sample: DR-3_20130425 Date: 4/25/2013 Result [1]	Sample: DR-3_20130612 Date: 6/12/2013 Result [1]	Sample: DR-3_20130710 Date: 7/10/2013 Result [1]	Sample: DR-3_20130827 Date: 8/27/2013 Result [1,2]
Metals					
Aluminum, Total	µg/L	1,020	901	372	822
Aluminum, Dissolved	µg/L	51.2	30.4	23.0	20.6
Antimony, Total	µg/L	< 0.50	< 0.50	< 0.50	<0.50
Antimony, Dissolved	µg/L	< 0.50	< 0.50	< 0.50	<0.50
Arsenic, Total	µg/L	2.4	1.8	0.70	1.5
Arsenic, Dissolved	µg/L	< 0.50	< 0.50	< 0.50	<0.50
Barium, Total	µg/L	22.7	21.7	18.9	21.9
Barium, Dissolved	µg/L	20.2	21.0	20.3	19.9
Beryllium, Total	µg/L	1.1	1.1	0.56	0.85
Beryllium, Dissolved	µg/L	0.33	0.32	0.34	0.31
Cadmium, Total	µg/L	19.0	24.1	18.1	21.1
Cadmium, Dissolved	µg/L	15.4	20.5	19.2	18.9
Calcium, Total	µg/L	293,000	243,000	311,000	263,000
Calcium, Dissolved	µg/L	257,000	239,000	229,000	256,000
Chromium, Total	µg/L	0.57	0.54	< 0.50	<0.50
Chromium, Dissolved	µg/L	0.70	0.56	< 0.50	<0.50
Cobalt, Total	µg/L	3.2	2.9	2.5	2.8
Cobalt, Dissolved	µg/L	2.8	2.8	2.7	2.7
Copper, Total	µg/L	170	184	80.2	179
Copper, Dissolved	µg/L	12.9	9.1	8.6	8.1
Hardness, Total	mg/L	811	688	849	741
Iron, Total	µg/L	12,400	9,040	4,600	8,380
Iron, Dissolved	µg/L	1,420	285	428	315
Lead, Total	µg/L	25.0	17.0	5.7	15.6
Lead, Dissolved	µg/L	1	0.25	< 0.10	<0.10
Lithium, Total	µg/L	NA	NA	NA	NA
Lithium, Dissolved	µg/L	NA	NA	NA	NA
Magnesium, Total	µg/L	19,600	19,800	17,600	20,500
Magnesium, Dissolved	µg/L	19,100	19,500	18,700	20,400
Manganese, Total	µg/L	1,890	1,930	2,170	1,910
Manganese, Dissolved	µg/L	1,760	1,860	1,820	1,820
Mercury	µg/L	< 0.20	< 0.20	< 0.20	<0.20
Mercury, Dissolved	µg/L	< 0.20	< 0.20	< 0.20	<0.20
Molybdenum, Total	µg/L	17.4	16.4	17.8	17.4
Molybdenum, Dissolved	µg/L	14.6	13.8	18.6	14.9
Nickel, Total	µg/L	4.0	4.6	3.9	4.2
Nickel, Dissolved	µg/L	7.8	4.8	4.7	6.0
Potassium, Total	µg/L	5,420	4,020	3,660	3,330
Potassium, Dissolved	µg/L	5,360	3,970	3,480	3,280
Selenium, Total	µg/L	< 0.50	< 0.50	< 0.50	<0.50
Selenium, Dissolved	µg/L	< 0.50	< 0.50	< 0.50	<0.50
Silica, Total	µg/L	20,500	19,600	20,100	19,500
Silica, Dissolved	µg/L	NA	NA	NA	NA
Silver, Total	µg/L	< 0.50	< 0.50	< 0.50	<0.50
Silver, Dissolved	µg/L	< 0.50	< 0.50	< 0.50	<0.50

TABLE 2-3
ANALYTICAL AND FIELD MONITORING RESULTS
2012-2013 BLAINE TUNNEL AND SELECTED DR-3 WATER SAMPLES
EVALUATION OF SOURCE WATER CONTROLS
Rico-Argentine Mine Site
Dolores County, Colorado

Parameter	Units	Sample: DR-3_20130425 Date: 4/25/2013 Result [1]	DR-3_20130612 6/12/2013 Result [1]	DR-3_20130710 7/10/2013 Result [1]	DR-3_20130827 8/27/2013 Result [1,2]
Sodium, Total	µg/L	14,000	11,600	26,800	14,300
Sodium, Dissolved	µg/L	11,800	11,300	22,600	14,900
Thallium, Total	µg/L	< 0.10	< 0.10	< 0.10	<0.10
Thallium, Dissolved	µg/L	< 0.10	< 0.10	< 0.10	<0.10
Vanadium, Total	µg/L	0.21	0.17	< 0.10	0.18
Vanadium, Dissolved	µg/L	< 0.10	< 0.10	< 0.10	<0.10
Zinc, Total	µg/L	4,050	4,620	4,220	4,080
Zinc, Dissolved	µg/L	3,230	3,930	3,620	3,640
General Water Chemistry and Anions					
Alkalinity, Bicarbonate	mg/L as $CaCO_3$	95.0	90.8	95.9	144
Alkalinity, Carbonate	mg/L as $CaCO_3$	< 20.0	< 20.0	< 20.0	< 20.0
Alkalinity, Hydroxide	mg/L as $CaCO_3$	NA	NA	NA	NA
Alkalinity, Total	mg/L as $CaCO_3$	95.0	90.8	95.9	144
Total Dissolved Solids	mg/L	920	980	988	1,110
Total Suspended Solids	mg/L	19.0	29.0	15.0	22.0
Sulfide, Total	mg/L	< 0.050	< 0.050	< 0.050	< 0.050
Bromide	mg/L	NA	NA	NA	NA
Chloride	mg/L	< 1.0	< 1.0	< 1.0	1.4
Fluoride	mg/L	NA	NA	NA	NA
Sulfate	mg/L	687	774	660	604
Nitrogen, Nitrate	mg/L	< 0.10	< 0.10	< 0.10	0.13
Total Organic Carbon	mg/L	< 1.0	< 0.50	< 0.50	< 0.50
Field Monitoring Parameters					
pH	standard units	7.13	6.89	7.15	6.54
Temperature	˚C	16.98	20.08	20.02	6.55
Conductivity	µS/cm	1,422	1,474	1,466	1,342
Dissolved Oxygen	mg/L	1.59	5.8	2.97	5.29
Oxidation Reduction Potential	mV	-47.1	-11.7	-37.9	-22.3

Notes

1. DR-3 data provided by Anderson Engineering Company. Only DR-3 data used to perform mass loading calculations was included herein.

2. Preliminary data set.

Abbreviations:

˚C = degrees Celsius

< = analyzed but not detected above the method reporting limit shown

$CaCO_3$ = calcium carbonate

J = result is above method detection limit but below reporting limit

mg/L = milligram per liter

mV = millivolt

NA = not analyzed

µg/L = microgram per liter

µS/cm = microSiemen per centimeter

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TABLE 2-4
COMPARISON OF BLAINE TUNNEL AND ST. LOUIS TUNNEL
CONTAMINANT DISCHARGE RATES
EVALUATION OF SOURCE WATER CONTROLS
Rico-Argentine Mine Site
Dolores County, Colorado

Location	Loading Rates Blaine[3]	DR-3[4]	Blaine Loading Contribution[5]	Loading Rates Blaine[3]	DR-3[4]	Blaine Loading Contribution[5]	Loading Rates Blaine[3]	DR-3[4]	Blaine Loading Contribution[5]	Loading Rates Blaine[3]	DR-3[4]	Blaine Loading Contribution[5]	Loading Rate Blaine[3]
Sample Date	4/30/2013	4/25/2013	April 2013	6/19/2013	6/12/2013	June 2013	7/9/2013	7/10/2013	July 2013	8/21/2013	8/27/2013	August 2013	Peak[6]
Flow Rate[1,2] (gpm)	0.03	498	Estimated Range	0.11	543	Estimated Range	0.13	509	Estimated Range	0.32	539	Estimated Range	3.0
Analyte	(g/d)	(g/d)	lower upper	(g/d)	(g/d)	lower upper	(g/d)	(g/d)	lower upper	(g/d)	(g/d)	lower upper	(g/d)
Arsenic, Total	0.4 - 0.8	6.5	6% - 12%	0.4 - 0.8	5.3	7% - 15%	0.4 - 0.9	1.9	21% - 46%	1.2 - 2.5	4.4	27% - 57%	40 - 80
Arsenic, Dissolved[7]	0.4 - 0.8	1.4	29% - 59%	0.4 - 0.7	1.5	27% - 47%	0.4 - 0.9	1.4	29% - 65%	1.2 - 2.4	1.5	82% - 163%	40 - 90
Cadmium, Total	0.4 - 0.8	52	0.8% - 2%	1.2 - 2.3	71	2% - 3%	1.1 - 2.3	50	2% - 5%	3.1 - 6.2	62	5% - 10%	50 - 90
Cadmium, Dissolved	0.4 - 0.9	42	1% - 2%	1.2 - 2.5	61	2% - 4%	1.1 - 2.3	53	2% - 4%	3 - 6.1	56	5% - 11%	50 - 90
Iron, Total	330 - 650	33,700	1% - 2%	1200 - 2500	26,800	4% - 9%	1200 - 2300	12,800	9% - 18%	2500 - 5000	24,600	10% - 20%	36000 - 71000
Iron, Dissolved	340 - 670	3,860	9% - 17%	1500 - 3000	845	178% - 355%	1100 - 2300	1,190	92% - 193%	2500 - 5000	926	270% - 540%	37000 - 74000
Manganese, Total	20 - 40	5,140	0.4% - 1%	70 - 140	5,510	1% - 3%	70 - 150	6,020	1% - 2%	180 - 360	5,610	3% - 6%	2100 - 4200
Manganese, Dissolved	20 - 40	4,790	0.4% - 1%	70 - 150	5,720	1% - 3%	70 - 150	5,050	1% - 3%	190 - 370	5,350	4% - 7%	2200 - 4300
Zinc, Total	70 - 130	11,000	1% - 1%	180 - 360	11,600	2% - 3%	160 - 330	11,700	1% - 3%	350 - 690	12,000	3% - 6%	7300 - 15000
Zinc, Dissolved	70 - 130	8,780	1% - 1%	180 - 350	13,700	1% - 3%	160 - 330	10,000	2% - 3%	340 - 680	10,700	3% - 6%	7100 - 14000

Notes:

1. Flume flow rates were determined from depths measured by an ultrasonic sensor positioned above a flume. Flume average flow rates were calculated by averaging the hourly flow rates for the 24-hour period on which the sampling event occurred.

2. Average flow rate for the date that samples were collected, based on data reported by AECI. Flume average flow rates were calculated by averaging the flow rates recorded every 15 minutes for the date on which the sampling event occurred.

3. Blaine mass loading rate estimates assumed that all flow to the Humboldt Drift passed through the Blaine flume (lower-end of the range) or was added by the inflow immediately out-by (down-gradient) of the flume (upper-end of the range). Mass loading rates for the lower-end of the range were determined by multiplying the analyte concentration measured out-by of the flume during a sampling event with the flume average flow rate for the corresponding date. Upper-end values were determined by multiplying the analyte concentration measured out-by of the flume with two times the flume average flow rate. The upper-end values reflect maximum mass loading estimates, assuming that the flow rate for the inflow located out-by of the flume equals the flume flow rate.

4. St. Louis Tunnel mass loading rate estimates are equal to the product of the average flow rate and the reported concentration for samples collected from the DR-3 or DR-3A sampling location, immediately downstream of the St. Louis Tunnel portal.

5. Blaine loading contribution to the St. Louis Tunnel discharge was estimated by dividing Blaine mass loading rates by DR-3 mass loading rates.

6. Peak mass loading rates were estimated based on maximum detected flow rates and analyte concentrations. Peak flow through the flume was recorded on January 18, 2013; peak concentrations for the analytes presented herein corresponded to the April 30, 2013, sampling event.

7. Loading calculations are based on the laboratory reporting limit for this analyte; analyte was not detected in samples from DR-3 above the reporting limit.

Abbreviations:
gpm = gallon per minute
g/d = gram per day

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TABLE 4-1
FLOW AND CONTAMINANT LOADING CONTRIBUTIONS
AND SOLIDS GENERATION ESTIMATES
EVALUATION OF SOURCE WATER CONTROLS
Rico-Argentine Mine Site
Dolores County, Colorado

Parameter	St. Louis Tunnel Discharge at DR-3[1]					SE Cross-cut[3]					Combined NW Cross-cut and 145 Raise[4]					517 Shaft Treatment Scenario[5]	
	Concentration (µg/L)	Flow Rate (gpm)	Metals Loading Rate[2] (lb/day)	Sludge Production Rate[2] (lb/day)	Percent of Total Sludge[2]	Concentration (µg/L)	Estimated Flow Rate (gpm)	Metals Loading Rate[2] (lb/day)	Percent of DR-3 Metals Loading	Sludge Production Rate[2] (lb/day)	Estimated Concentration (µg/L)	Estimated Flow Rate (gpm)	Metals Loading Rate[2] (lb/day)	Percent of DR-3 Metals Loading	Sludge Production Rate[2] (lb/day)	DR-3 Concentration (µg/L)	Percent Reduction at DR-3 (by Parameter)
Aluminum	956	530	6.1	13.8	0.3%	76.4	353	0.32	5%	0.7	2,715	177	5.8	95%	13.0	905	5.3%
Cadmium	23.4	530	0.15	0.19	0.0%	9.4	353	0.040	27%	0.05	51.4	177	0.11	73%	0.14	17.1	27%
Calcium	245,000	530	1,600	4,000	89.3%	312,000	353	1,320	83%	3,300	128,625	177	270	18%	675	42,875	83%
Copper	194	530	1.2	1.9	0.0%	16.1	353	0.068	6%	0.1	549.8	177	1.2	94%	1.8	183	5.5%
Iron	8,490	530	54	86	1.9%	719	353	3.1	6%	5	24,032	177	51	94%	81	8,011	5.6%
Magnesium	20,300	530	130	312	7.0%	26,300	353	110	85%	264	9,369	177	20	15%	48	3,123	85%
Manganese	1,840	530	12	24	0.5%	1,170	353	5.0	42%	10	3,180	177	6.7	58%	14	1,060	42%
Zinc	4,340	530	28	42	1%	2,990	353	13	46%	19	7,040	177	15	54%	23	2,347	46%
Totals (lbs/d)			**1,831**	**4,480**		**SE Cross-cut (lbs/d)**		**1,451**		**3,599**	**NW Cross-cut (lbs/d)**		**370**		**856**		

Notes

1. DR-3 concentrations are from sample DR3A130619, collected on June 19, 2013, at monitoring location DR-3A. The DR-3 flow rate was measured manually on June 12, 2013.
2. Metals loading rate is the product of flow and concentration. Sludge production rate assumes full precipitation of analytes as solids.
3. SE Cross-cut concentrations are from sample 517SHAFT465130619, collected on June 19, 2013, from the 517 Shaft. Flow rate assumes that 67% of DR-3 flow originates from the SE cross-cut, per Anaconda (1982).
4. NW Cross-cut concentrations are calculated based on DR-3 and SE Cross-cut concentrations, assuming that 33% of DR-3 flow originates from the NW Cross-cut and 145 Raise, per Anaconda (1982), and the balance of mass loading not originating from the SE Cross-cut is contributed by the combined flow from the NW Cross-cut and 145 Raise.
5. This scenario assumes full removal of metals concentrations from the SE Cross-cut by treatment at the 517 Shaft. Predicted DR-3 concentrations were calculated by dividing the estimated mass load from the combined NW Cross-cut and 145 Raise by the flow rate at DR-3.

Abbreviations
% = percent
gpm = gallon per minute
lbs/d = pound per day
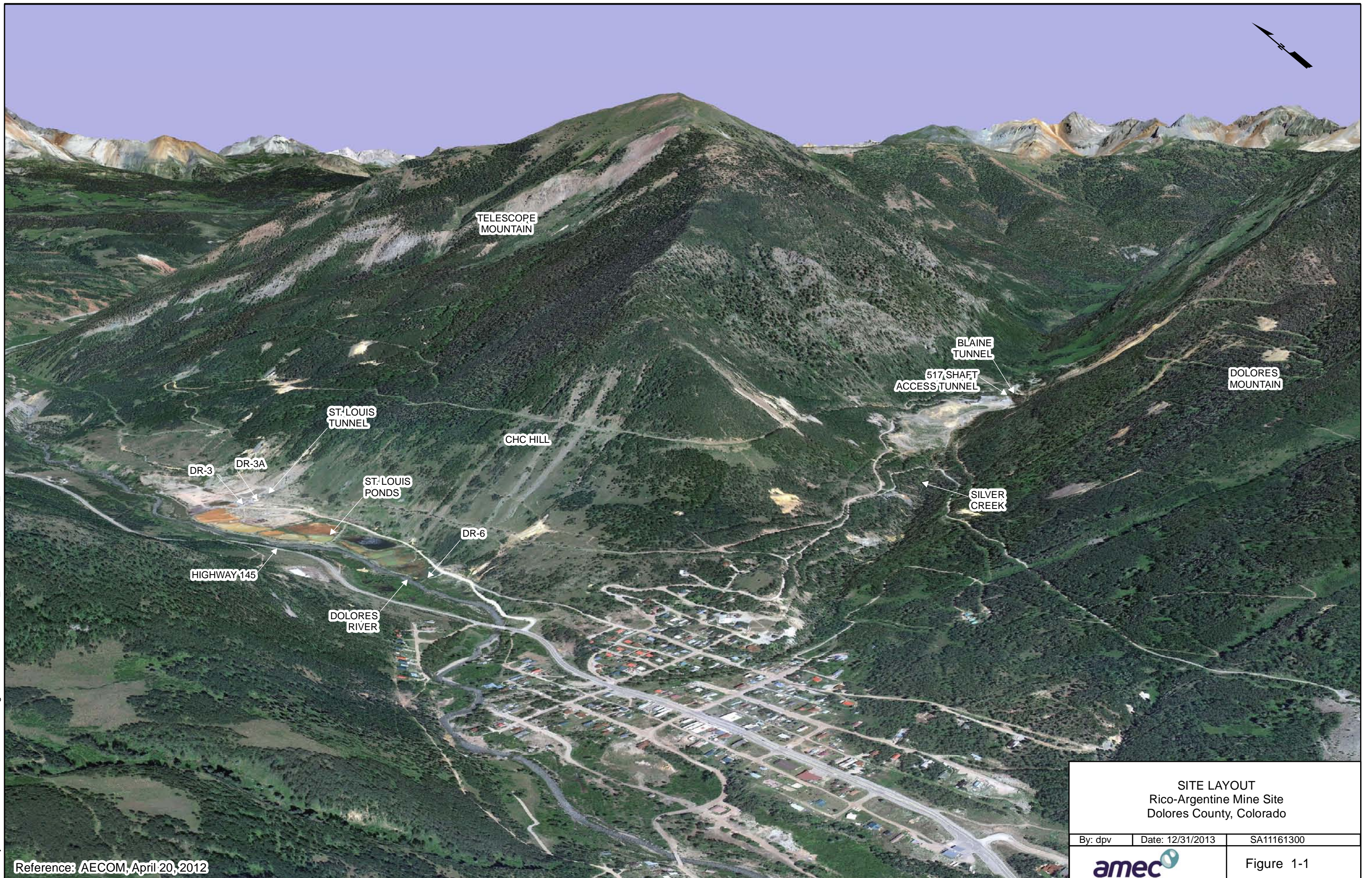µg/L = microgram per liter

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FIGURES

TELESCOPE
MOUNTAIN

BLAINE
TUNNEL

517 SHAFT
ACCESS TUNNEL

DOLORES
MOUNTAIN

ST. LOUIS
TUNNEL

CHC HILL

DR-3   DR-3A

SILVER
CREEK

ST. LOUIS
PONDS

DR-6

HIGHWAY 145

DOLORES
RIVER

Reference: AECOM, April 20, 2012

SITE LAYOUT
Rico-Argentine Mine Site
Dolores County, Colorado

By: dpv	Date: 12/31/2013	SA11161300

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Figure 1-1

LEGEND:

———	ST. LOUIS/500 LEVEL
———	PIGEON LEVEL
———	MOUNTAIN SPRINGS LEVEL
———	9465 LEVEL
———	WELLINGTON LEVEL
———	BLAINE LEVEL
———	200 LEVEL
———	300 LEVEL
———	400 LEVEL
———	600 LEVEL
———	700 LEVEL

0   1000'

PIGEON TUNNEL PORTAL

9465 LEVEL (MTN SPRINGS)

NW CROSS-CUT / NORTH DRIFT (ST. LOUIS LEVEL)

MOUNTAIN SPRINGS TUNNEL PORTAL

145 RAISE (ST. LOUIS)

WELLINGTON TUNNEL PORTAL

ST. LOUIS TUNNEL

TUNNEL INTERSECTION

CO HIGHWAY 145

DOLORES RIVER

DR-3

ST. LOUIS TUNNEL PORTAL (DR-3A)

517 SHAFT (INJECTION AND SAMPLING LOCATION)

SE CROSS-CUT (ST. LOUIS LEVEL)

ARGENTINE SHAFT TUNNEL PORTAL (NO OPENING VISIBLE FROM GROUND SURFACE)

ARGENTINE SHAFT (NOT VISIBLE AT SURFACE)

517 SHAFT ACCESS TUNNEL PORTAL

DR-6

SILVER CREEK

BLAINE TUNNEL PORTAL

TOWN OF RICO

ST. LOUIS TUNNEL DISCHARGE
SOURCE TREATABILITY STUDY
MINE WORKINGS LAYOUT
Rico-Argentine Mine Site
Dolores County, Colorado

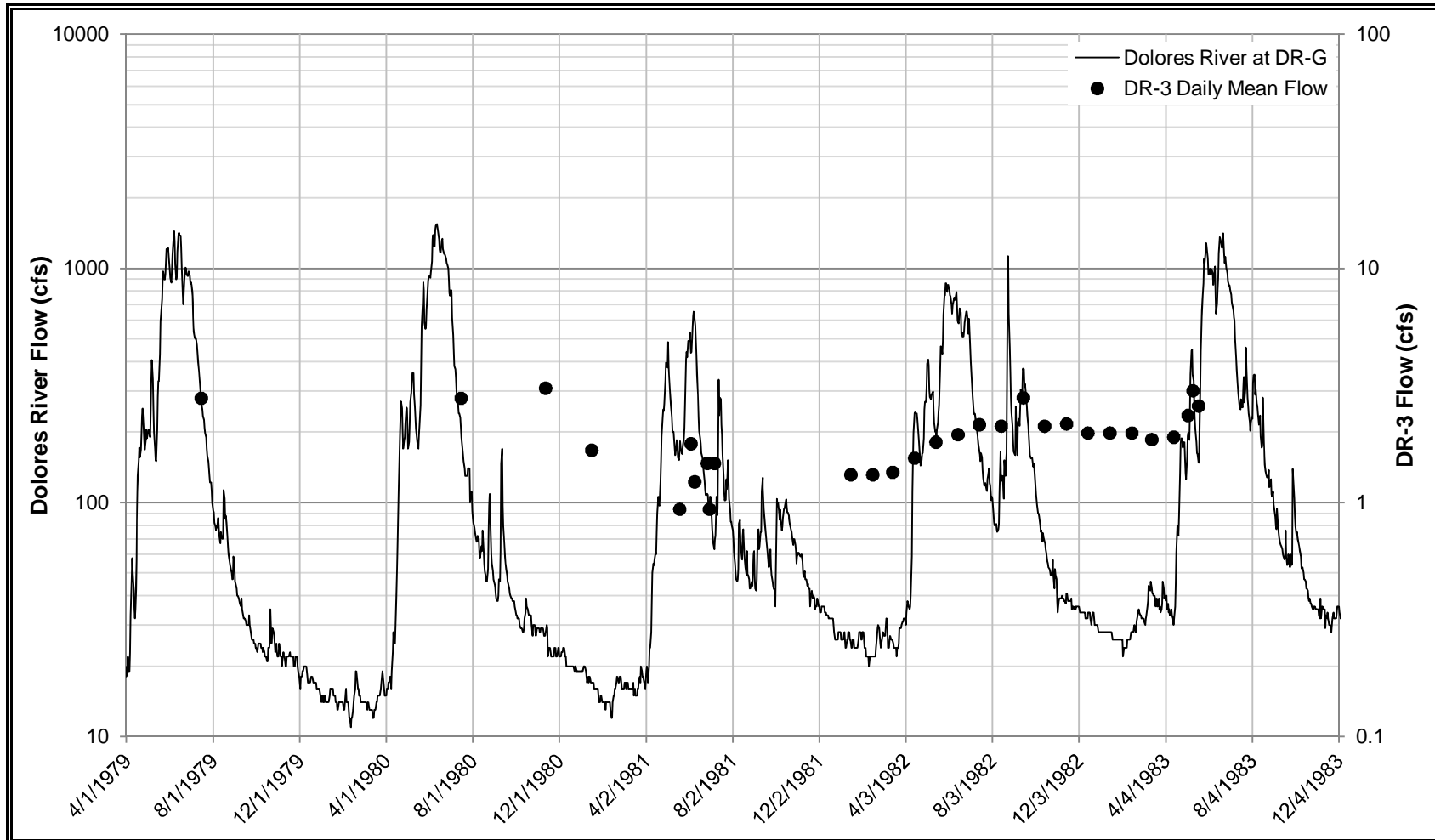| By: dpv	Date: 12/31/2013	SA11161313

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Figure 1-2

Reference: AECOM, April 20, 2012

P:\Project\16000s\SA11161300 - Rico-Argentine Mine Site\14000_CAD\Blaine Tunnel\1-2_MINEWORKINGSLAYOUT.mxd
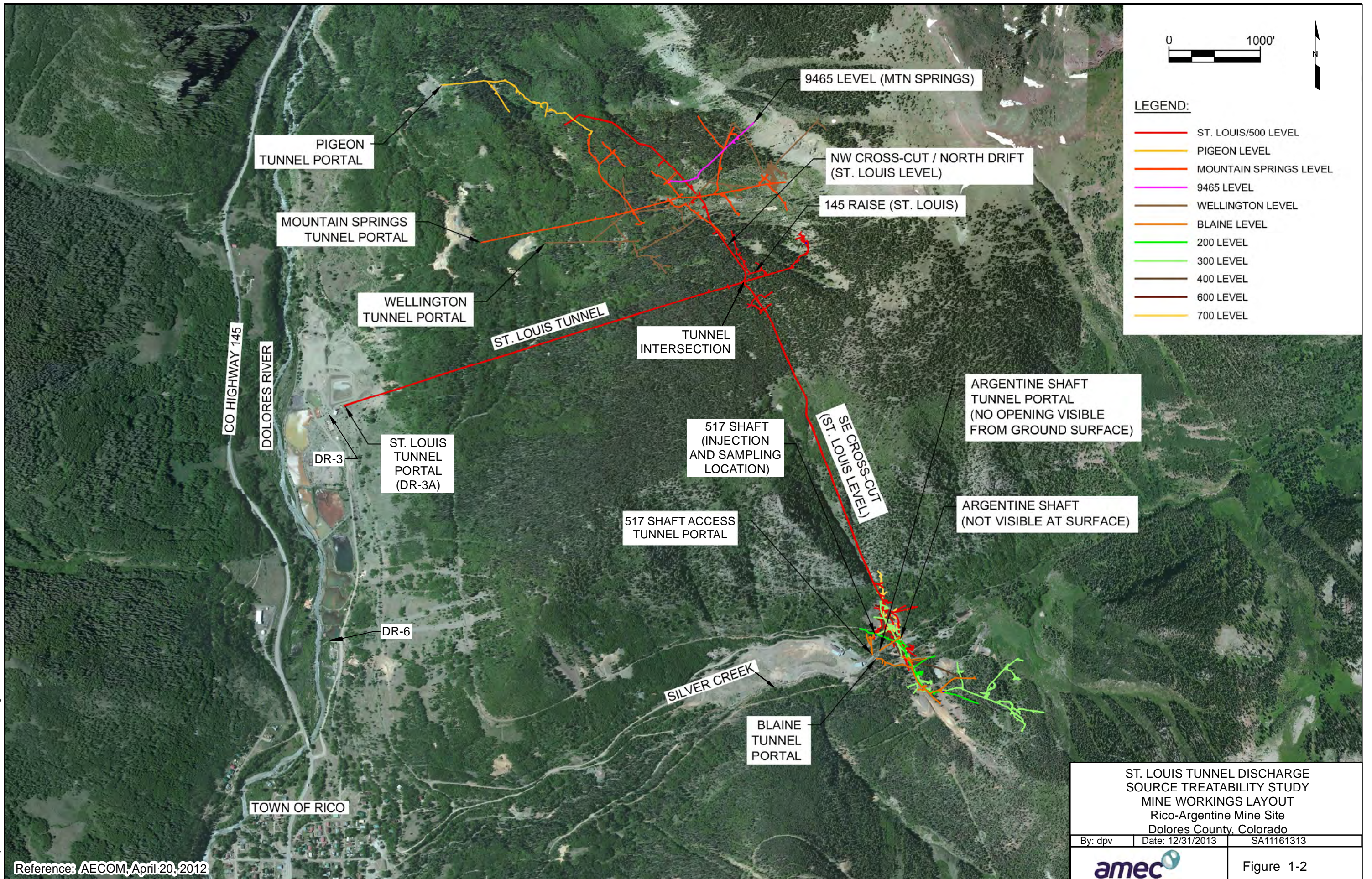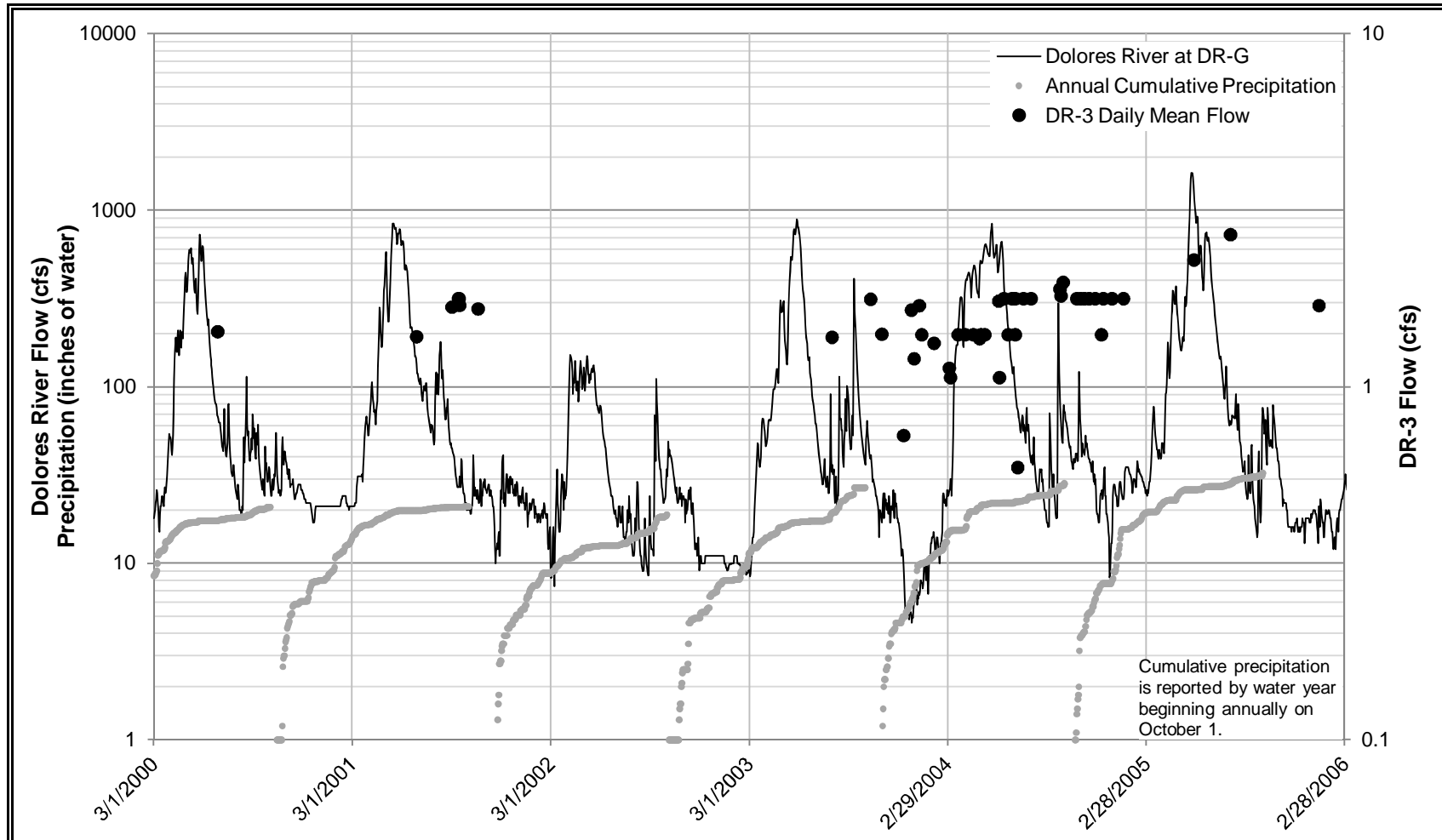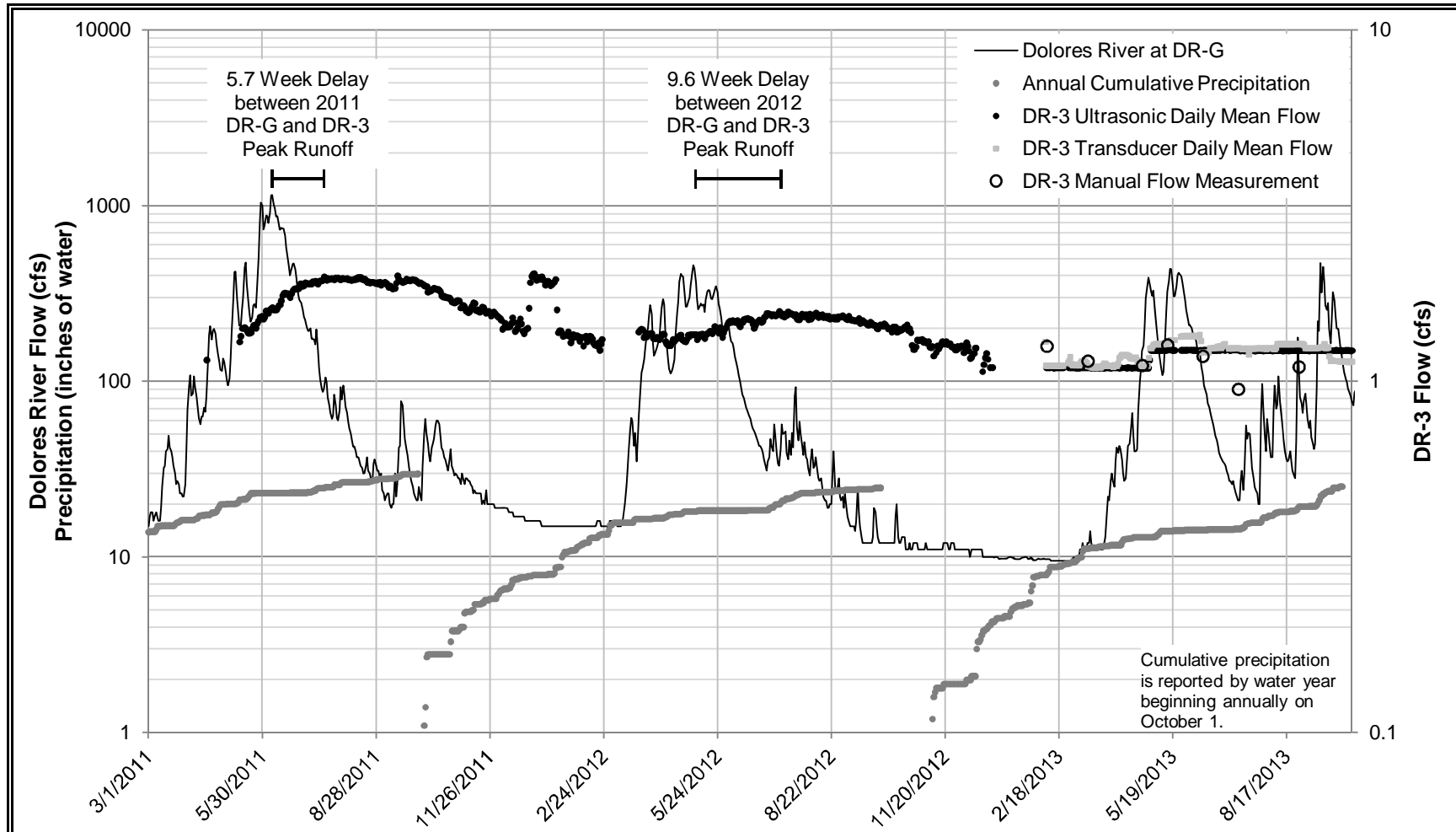
FIGURE 2-1
1979-1983 FLOW RATES
ST. LOUIS TUNNEL DISCHARGE AND DOLORES RIVER
EVALUATION OF SOURCE WATER CONTROLS
Rico-Argentine Mine Site
Dolores County, Colorado

FIGURE 2-2
2000-2006 FLOW RATES
ST. LOUIS TUNNEL DISCHARGE AND DOLORES RIVER
EVALUATION OF SOURCE WATER CONTROLS
Rico-Argentine Mine Site
Dolores County, Colorado

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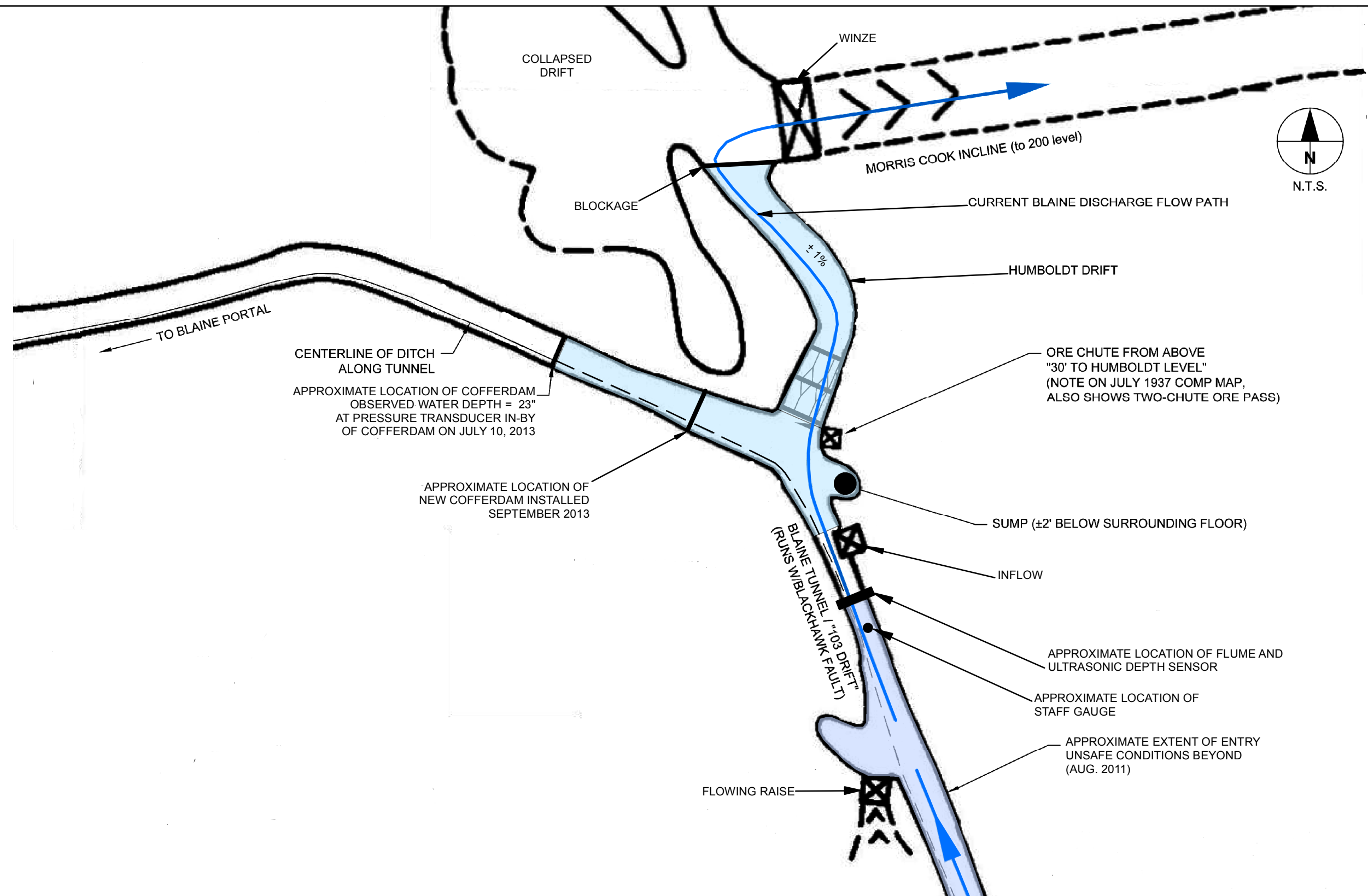
Page 1 of 1

FIGURE 2-3
2011-2013 FLOW RATES
ST. LOUIS TUNNEL DISCHARGE AND DOLORES RIVER
EVALUATION OF SOURCE WATER CONTROLS
Rico-Argentine Mine Site
Dolores County, Colorado

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WINZE

COLLAPSED DRIFT

MORRIS COOK INCLINE (to 200 level)

CURRENT BLAINE DISCHARGE FLOW PATH

BLOCKAGE

HUMBOLDT DRIFT

N.T.S.

+ 1%

TO BLAINE PORTAL

CENTERLINE OF DITCH
ALONG TUNNEL

ORE CHUTE FROM ABOVE
"30' TO HUMBOLDT LEVEL"
(NOTE ON JULY 1937 COMP MAP,
ALSO SHOWS TWO-CHUTE ORE PASS)

APPROXIMATE LOCATION OF COFFERDAM
OBSERVED WATER DEPTH = 23"
AT PRESSURE TRANSDUCER IN-BY
OF COFFERDAM ON JULY 10, 2013

APPROXIMATE LOCATION OF
NEW COFFERDAM INSTALLED
SEPTEMBER 2013

SUMP (±2' BELOW SURROUNDING FLOOR)

INFLOW

BLAINE TUNNEL / "103 DRIFT"
(RUNS W/BLACKHAWK FAULT)

APPROXIMATE LOCATION OF FLUME AND
ULTRASONIC DEPTH SENSOR

APPROXIMATE LOCATION OF
STAFF GAUGE

APPROXIMATE EXTENT OF ENTRY
UNSAFE CONDITIONS BEYOND
(AUG. 2011)

FLOWING RAISE

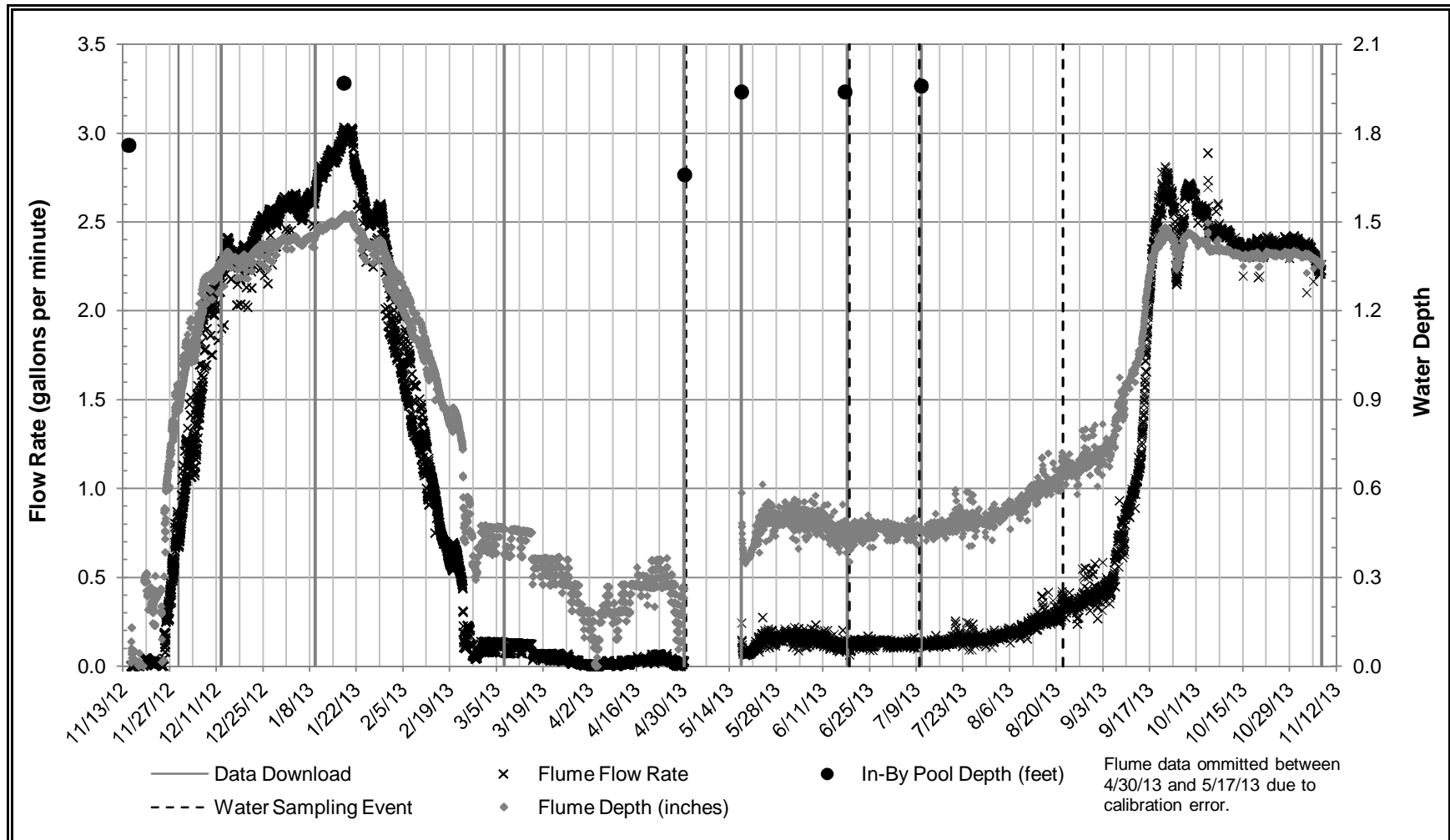P:\Project\16000s\SA11161300 - Rico-Argentine Mine Site\14000_CAD\Blaine Tunnel\Blaine_TunnelMap.mxd

BLAINE TUNNEL LAYOUT
EVALUATION OF SOURCE WATER CONTROLS
Rico-Argentine Mine Site
Dolores County, Colorado
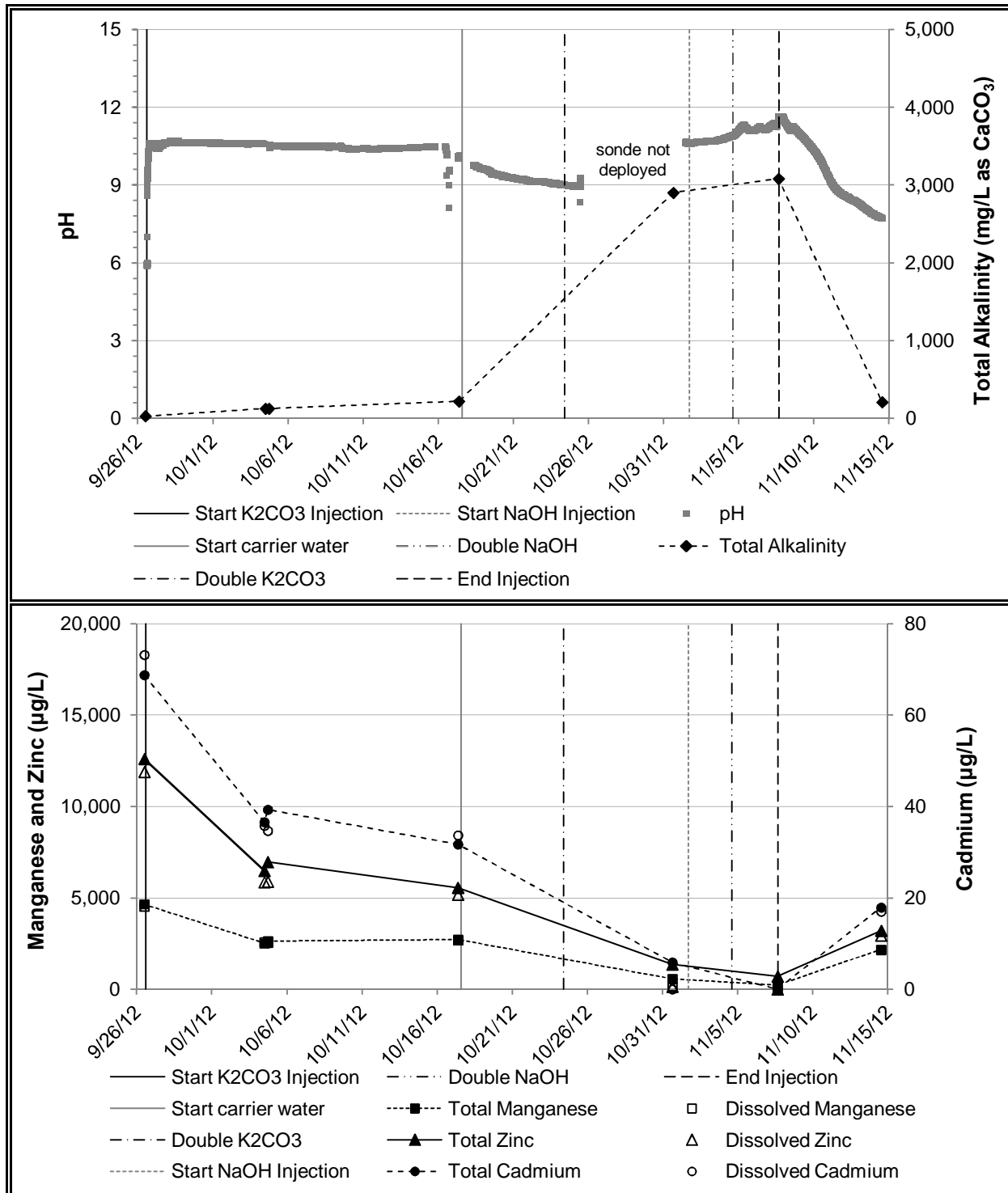
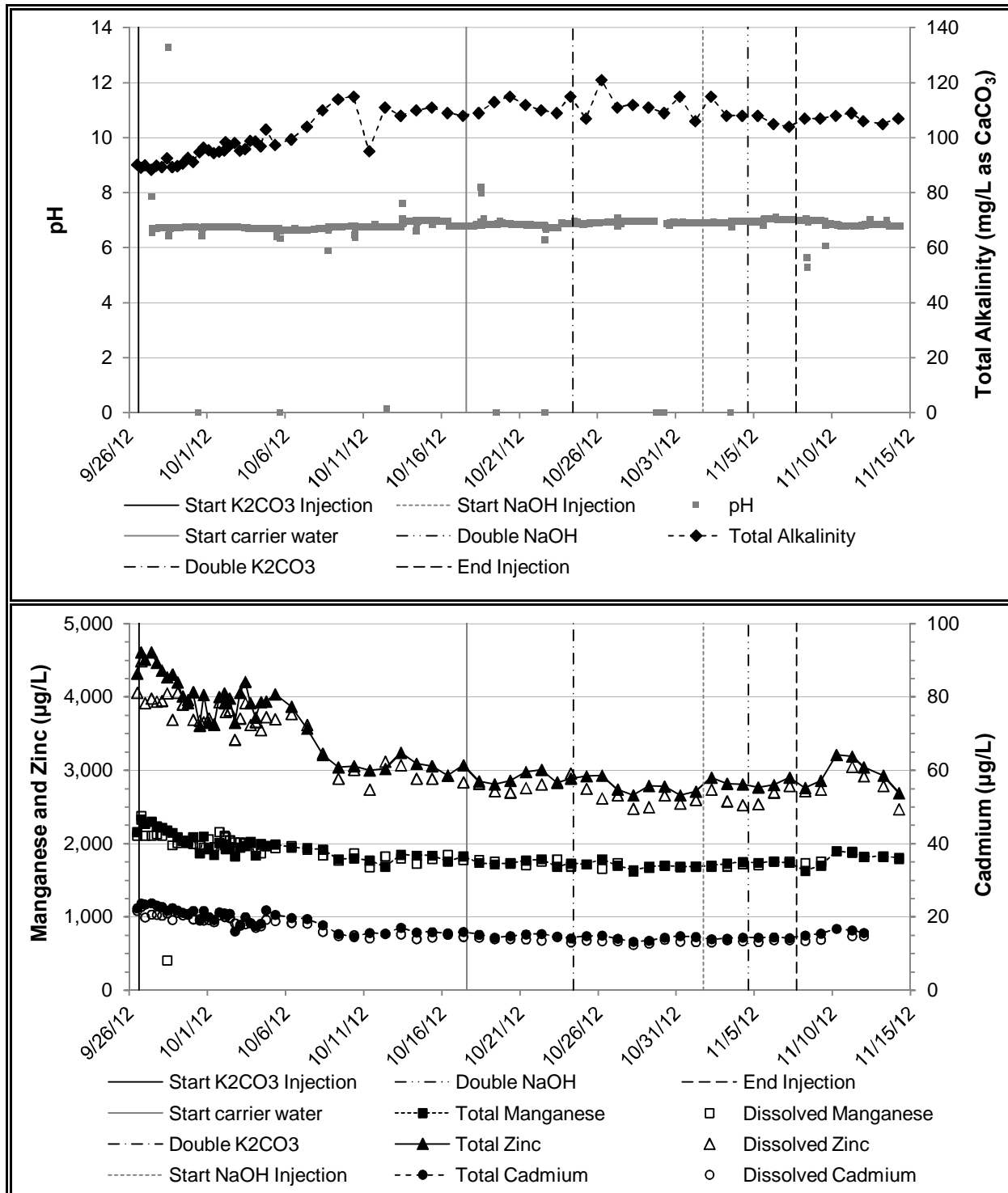By: DPV | Date: 12/31/2013 | Project No. SA11161300

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Figure | 2-4

FIGURE 2-5
BLAINE TUNNEL FLUME ULTRASONIC SENSOR
FLOW RATE AND WATER DEPTH: 2012-2013
EVALUATION OF SOURCE WATER CONTROLS
Rico-Argentine Mine Site
Dolores County, Colorado

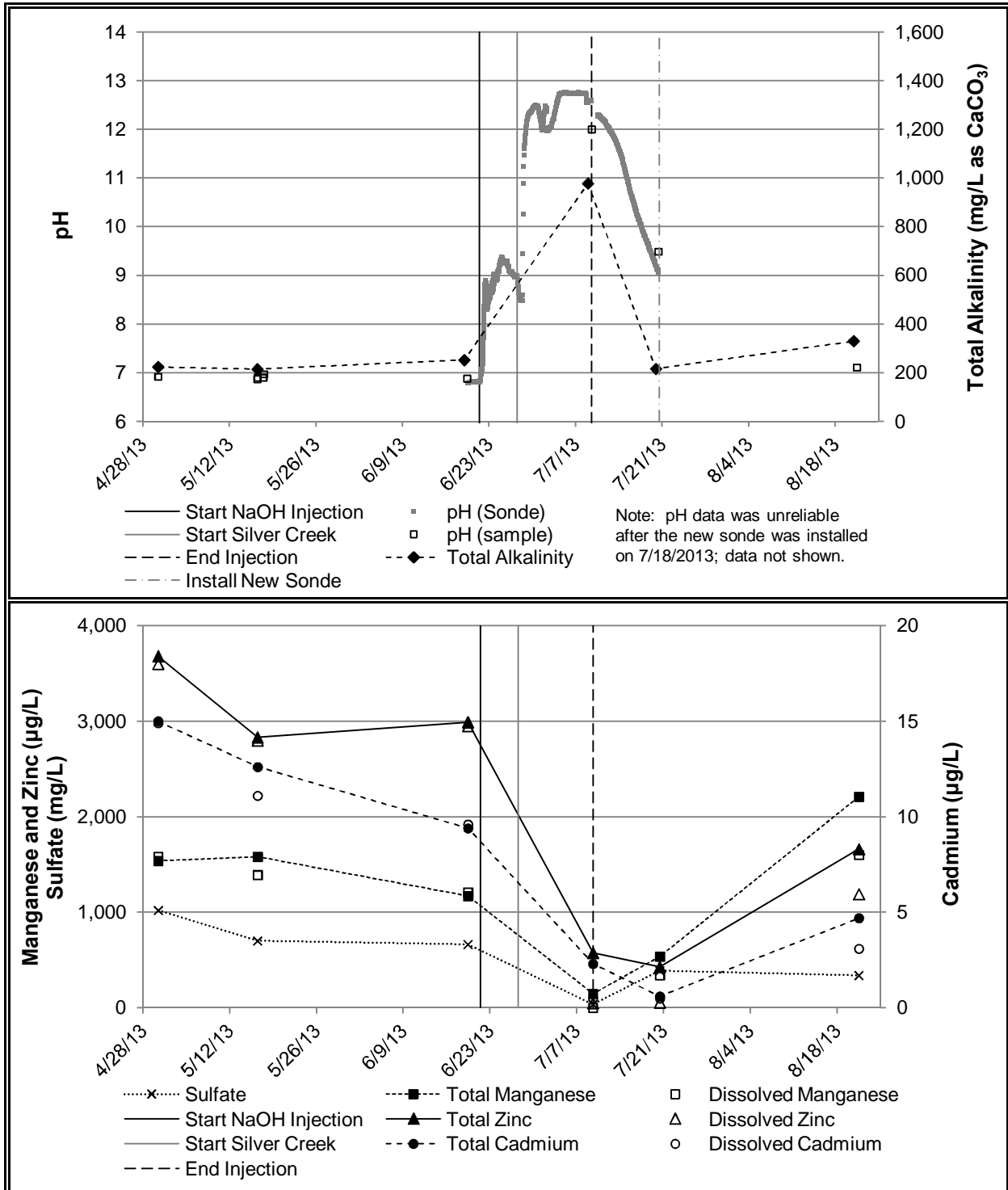AMEC Environment & Infrastructure, Inc.

FIGURE 4-1
2012 INJECTION TEST
517 SHAFT SELECT WATER QUALITY PARAMETERS AND ANALYTES
EVALUATION OF SOURCE WATER CONTROLS
Rico-Argentine Mine Site
Dolores County, Colorado

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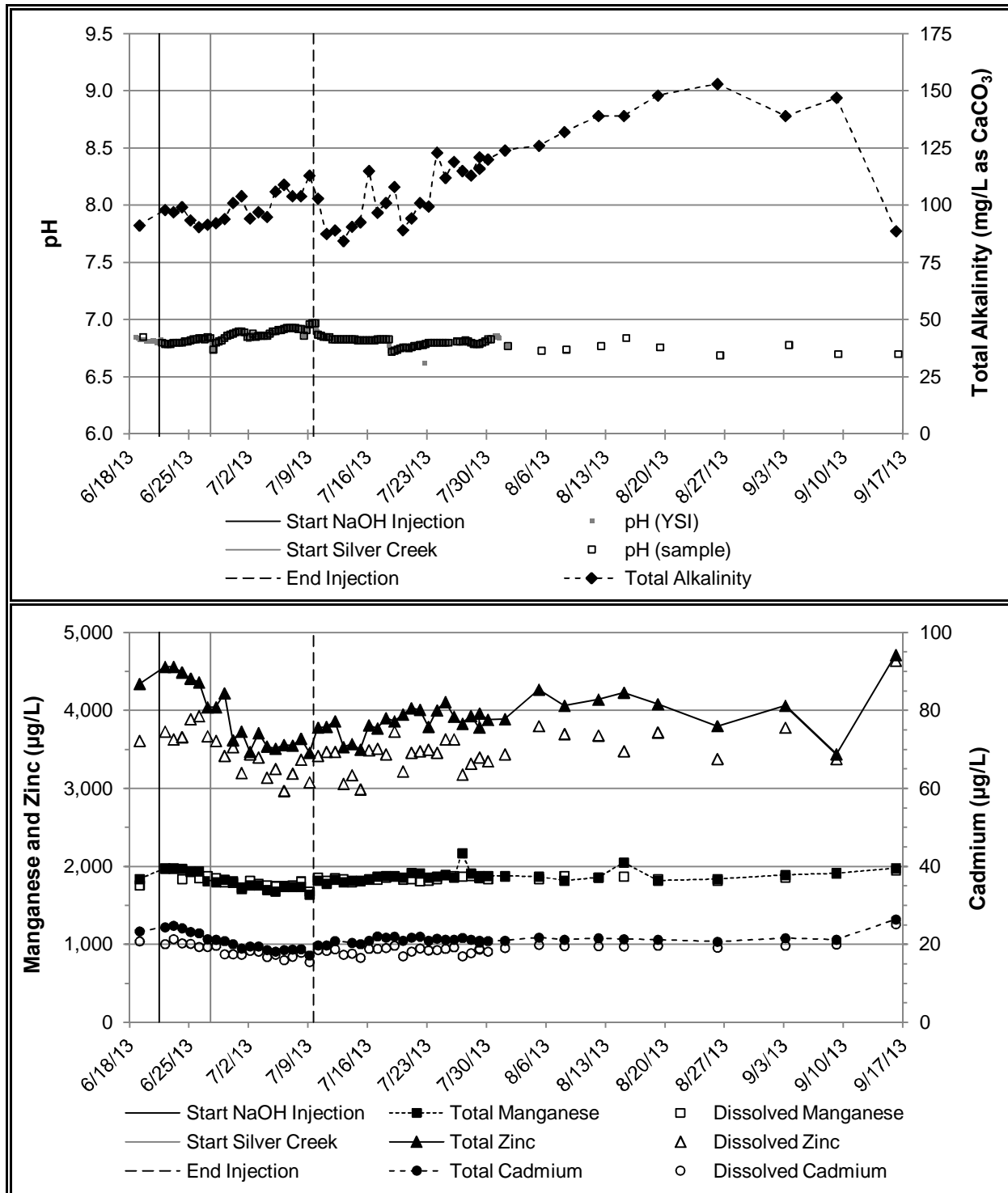Control\Fig_Tbl\Rico_SourceCtrl_F4-1_4-2_Trends2012_131231

FIGURE 4-2
2012 INJECTION TEST
DR-3A SELECT WATER QUALITY PARAMETERS AND ANALYTES
EVALUATION OF SOURCE WATER CONTROLS
Rico-Argentine Mine Site
Dolores County, Colorado

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FIGURE 4-3
2013 INJECTION TEST
517 SHAFT SELECT WATER QUALITY PARAMETERS AND ANALYTES
EVALUATION OF SOURCE WATER CONTROLS
Rico-Argentine Mine Site
Dolores County, Colorado

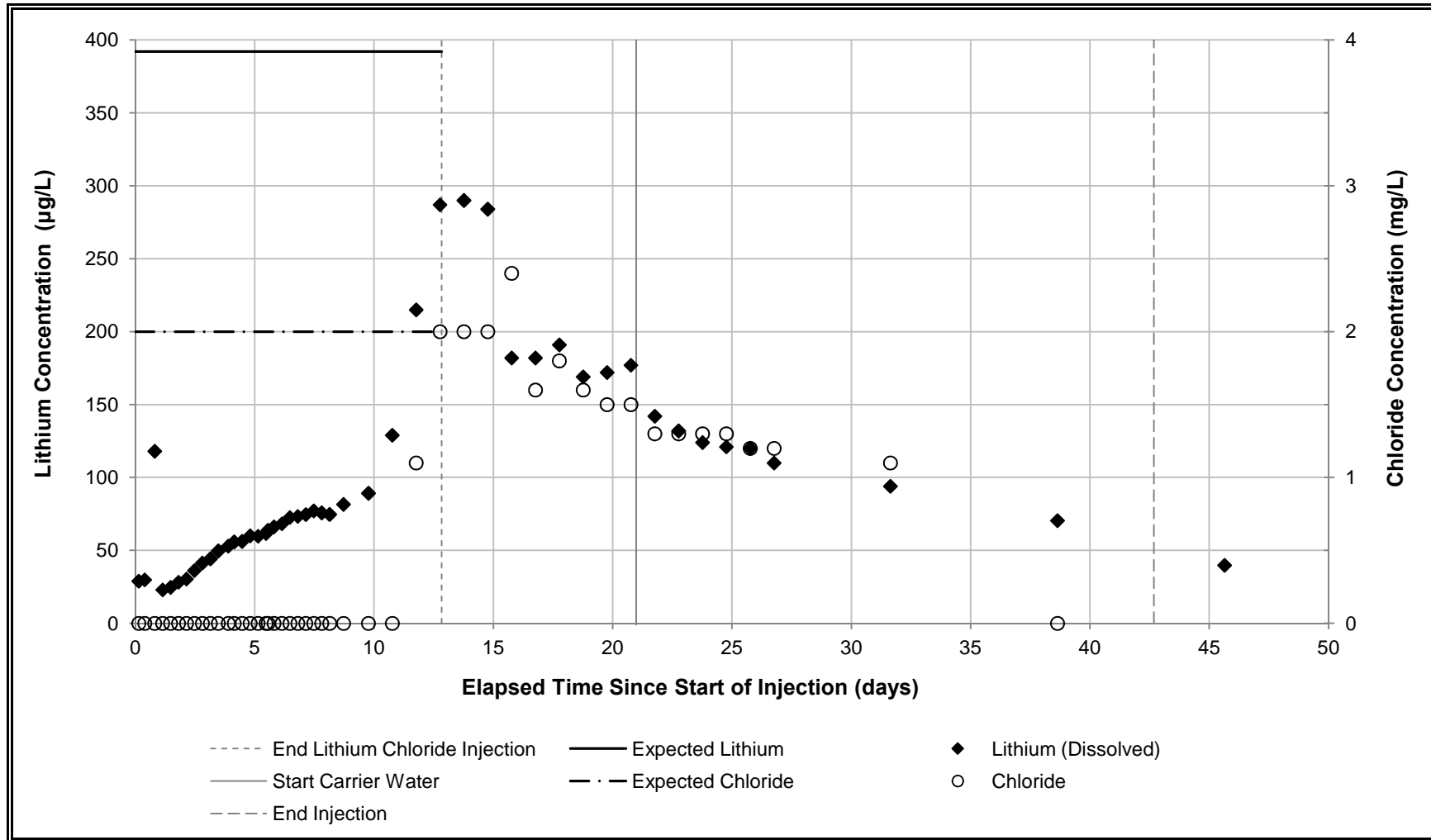AMEC Environment & Infrastructure, Inc.

FIGURE 4-4
2013 INJECTION TEST
DR-3A SELECT WATER QUALITY PARAMETERS AND ANALYTES
EVALUATION OF SOURCE WATER CONTROLS
Rico-Argentine Mine Site
Dolores County, Colorado

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Control\Fig_Tbl\Rico_SourceCtrl_F4-3_4-4_Trends2013_131231

FIGURE 4-5
2012 INJECTION TEST
TRACER TEST RESULTS AT DR-3A
EVALUATION OF SOURCE WATER CONTROLS
Rico-Argentine Mine Site
Dolores County, Colorado

AMEC Environment & Infrastructure, Inc.

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FIGURE 4-6
2013 INJECTION TEST
TRACER TEST RESULTS
EVALUATION OF SOURCE WATER CONTROLS
Rico-Argentine Mine Site
Dolores County, Colorado